THE

ROORKEE TREATISE

ON

CIVIL ENGINEERING IN INDIA.

EDITED BY

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VOL. II.

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PREFACE TO VOL. II.

Whoever reads this volume with a view to criticizing it, will find it, I doubt not, full of mistakes and omissions; I can only assure him that he cannot be more sensible of its defects than the compiler.

The subjects treated of are, indeed, so extensive that to do them justice, would require far more knowledge, both theoretical and practical, than I can pretend to. But I have endeavoured to supply a want which has long been felt by most Engineers in India, and have spared no pains in executing the task. Hereafter, perhaps, an improved edition may be issued more worthy of the subject, as well as the College from which it issues.

Many important branches of Engineering are wholly undiscussed in these two volumes, such as—Water Supply of Towns—Drainage—Harbour Works, and others. I can only say in excuse—first, that I know little or nothing about them; secondly, that they are subjects which do not generally enter into the practice of Indian Engineers; thirdly, that to have extended this Treatise would have been to make it too bulky and expensive for general use.

The First Volume having treated of Building Materials, their nature, uses and strength,—and the principles of general construction involved in Masonry, Carpentry and Earthwork,—this

Second Volume treats of Special Constructions under the headings—Buildings, Bridges, Roads, Railways and Irrigation Works.

Section VI., Buildings, has been compiled from the College Manual, No. VI., from Mahan, Rankine, and other sources; with some Indian examples taken from the "Professional Papers."

Sections VII., VIII., IX., and X., Bridges, Roads, Railways, and Irrigation Works, have been based on the four College Manuals, on those subjects, drawn up by myself in 1863, to which has been added a large quantity of additional matter and numerous Indian examples from the "Professional Papers," and other works noted below.

As the authorities from whom extracts have been made or opinions quoted, have not, as a rule, been given in the text, I will here add a list of the works consulted in the preparation of the two Volumes:—

Thomason College Manuals of Civil Engineering, Nos. I. to X.

Professional Papers on Indian Engineering, Vols. 1, 2 and 3.

Proceedings of the Institution of Civil Engineers.

Mahan's Treatise on Civil Engineering (American Edition).

Rankine's Manual of Civil Engineering.

Tredgold's Carpentry.

Dempsey's Practical Railway Engineer.

Gillespie's Roads and Railroads.

Humber's Wrought Iron Bridges.

Articles "Railways" and "Iron Bridges," in the Encyclopedia Britannica, 8th Edition.

Sir Proby Cautley's Report on the Ganges Canal.

Col. Dickens's Report on the Soane Canals.

Major Crofton's Reports on the Sultej and Ganges Canals.

Colonel Anderson's Notes on Canals and Rivers.

Professional Papers of Madras Engineers, Vols. 2 and 4.

Colonel Baird Smith's Madras Irrigation.

Keay's Scantlings of Timbers for Roofs.

Keay's Examples of Estimating.

Kunhya Lal's Wooden Bridges.

Morton's Treatise on Rajbuhas.

Interleaved copies of this Volume as well as the First, may be had on application. I may add that the first edition of Vol. I., of which only 500 copies were printed, will probably be exhausted in about a year, and if any interleaved copies with corrections and additions could be returned to Roorkee by the end of this year, I should esteem it a great favor, and would send in exchange copies of the new edition, when ready. Of the present volume 1000 copies have been printed, or the price of each would have been too heavy. A second edition of it, therefore, cannot be looked for so soon, but judging by the present demand even before the volume is issued, the date will not be a distant one when I shall be glad to have the interleaved copies returned with a similar object.

I take this opportunity of drawing attention to the care and excellence displayed in the Press-work of the two Volumes, for which the reader is indebted to Sergeant Johnston, the Superintendent of the College Press.

ROORKEE,
1st *May*, 1867.

J. G. M.

GLOSSARY OF INDIAN TERMS USED IN THIS TREATISE.

Anicut.—A weir built across a river to raise the level of the water for irrigation purposes.

Anna.—A copper coin, value 1½*d.*—16 make a rupee.

Beldar.—A digger—a "navvy."

Beegah.—A local land measure, varying much in different districts, but usually about three-fifths of an acre.

Bheestie.—A water-carrier.

Bhoosa.—Chopped straw.

Bhuttee.—A native kiln.

Budjeree.—A sort of gravel used in mortar.

Burgahs.—Joists used in flat roofing.

Bullah or *Bullee.*—A small tree, used as a scaffolding pole or as a pile.

Bund.— An embankment.

Calingula.—A waste weir by which surplus water is discharged from a tank.

Chatty.—A small earthen water-pot.

Chittack.—Two ounces—16 make a seer.

Chokut.—The outer frame of a door or window.

Coolie.—A common laborer.

Chunam.—Lime cement.

Daghbel.—A nicking cut in the ground.

Deodar—(*Cedrus deodara*).—A valuable wood, used in the Punjab; nearly the same as the Cedar of Lebanon.

Dhoob.—A species of grass.

Dhenkey.—A lever worked by a man's weight, and used to draw water, pound bricks, &c.

Doab.—A tract of country between two rivers.

Ghaut.—A mountain pass. 2. A river landing place.

Ghooting.—A kind of lime.

Grammie.—A thatcher; he also makes scaffolding.

Gunny.—Coarse sacking.

Jhama.—Vitrified brick.

Jham.—A peculiar tool used in well-sinking (*see* Vol. I., p. 213).

Khureef (fusl).—The autumn crop; sugar, rice, &c.

Kunkur.—A peculiar form of limestone found in the plains of Upper India, just below the surface, consisting of rough, irregular, nodules. It is used for road metalling, for burning into lime, for concrete and for building.

Kucha.—Raw, unburnt, unfinished.

Kurrie.—A small beam about 3 inches square.

Lakh.—100,000.

Laterite.—A peculiar sandy clay, used extensively in Southern India for building and road metalling.

Maund.—80 ℔s.—28 make a ton.

Mistree.—A master workman; *Raj mistree*, a master mason; *Burhaee mistree*, a master carpenter; *Lohar mistree*, a master blacksmith.

Moorum.—A kind of soft rock, used in the Bombay Presidency for metalling roads.

Monsoon.—The rainy season.

Musjid.—A mosque.

Nand.—A large earthen water-vessel.

Neemchuk.—The wooden ring on which the masonry of a well is built.

Nullah—Nuddee.—A water-course, full in the rains but dry during the greater part of the year.

Pajawah.—A native brick clamp.

Peela (bricks).—Bricks only half-burnt.

Pergunnah.—A sub-division of a Zillah or District.

Phowrah.—A large hoe, the common substitute for the spade, used all over India.

Pie.—A copper coin, value half-a-farthing—3 make one pice, and 4 pice make an anna.

Pucka.—Burnt, completed.

Pun-chukkee.—The native water-wheel, used in Upper India for grinding corn.

Punsal.—A water gauge.

Punkah.—A frame of wood and cloth, suspended from the ceiling of a room, and pulled by manual labor, to serve as a fan.

Rajbuha.—A minor water-course for Irrigation.

Rubbee (fusl).—The spring crop; wheat, &c.

Rupee.—A silver coin—worth about 2*s*.

Sâl or *Saul*—(*Shorea robusta*).—A strong tough wood, much used in building throughout the N. W. Provinces.

Seer.—2 lbs.—40 make a maund.

Soorkhee.—Pounded brick, used to mix in mortar.

Tope.—A clump of trees

Toon—(*Cedrela Toona*)—A wood resembling mahogany, and used for similar purposes

ERRATA.

Page 100, line 8, *for* the first $w\frac{l}{N}$ *read* $w\frac{2l}{N}$.

" " " 9, *for* " $w\frac{l}{N}$ *read* $w\frac{3l}{N}$.

" 201, " 1, *for* sine of the angle $= \frac{d \times \text{rad. of tables}}{r^2}$, *read* sin $\frac{1}{2}$ angle $= \frac{d}{2r}$.

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SECTION VI.—BUILDINGS.

MANY of the details of the *Construction of Buildings* have necessarily been treated of already in the Chapters on FOUNDATIONS, STONE and BRICK MASONRY, ROOFS, &c. In this Section, what remains to be added to the subject will be treated of under the heads of WALLS, FLOORS, ROOF COVERINGS, FINISHING and DESIGNING

CHAPTER XXIV.

WALLS.

1. *Foundation.*—The object of carrying the foundation of a building below the surface of the ground is to guard against the bottom of the masonry being exposed and undermined; and, where the soil is easily compressible, or loose, to obtain a firm footing. It is not essential that rock, or very hard soil, should be met with. A building may be secure even on sand, if it be carried down sufficiently to be beyond the chances of undermining by rain, &c., and the sand be not liable to lateral displacement. "Made earth"—that is, soil that has been dug and moved, must always be distrusted, and precautions taken proportional to the weight of the building to be put upon it.

For buildings of ordinary size and height, it is generally sufficient to dig down to a depth, to which the soil is not affected by rain in India, and by frost in England. In compressible soils it is sufficient for ordinary buildings that the soil should be equally compressible. In all cases, however, wherein the building varies much in the height, and consequent weight of particular parts, great care should be taken to adjust the areas to be compressed to the corresponding weight of each part. Where the soil

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CHAPTER XXIV.

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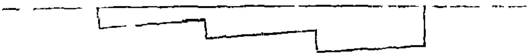
For buildings of ordinary size and height, it is generally sufficient to dig down to a depth, to which the soil is not affected by rain in India, and by frost in England. In compressible soils it is sufficient for ordinary buildings that the soil should be equally compressible. In all cases, however, wherein the building varies much in the height, and consequent weight of particular parts, great care should be taken to adjust the areas to be compressed to the corresponding weight of each part. Where the soil is unequal, the softer parts may be crossed by arches abutting on the harder, and where the weight of the building bears upon points, as in a colonnade, a continuous foundation is built with inverted arches between each pillar. Where the weight is great, and the ground soft, Concrete forms an excellent bed for a foundation when carefully laid; three measures of broken stone or well washed road kunkur, to one of good hydraulic mortar, carefully and equally mixed, kept wet, and rammed whilst setting, make a good concrete; or the kunkur may be used as in road making, and if well beaten will be found serviceable.

The excavation, on being dug to the required depth must, with great care, be made correctly level at bottom, both longitudinally and transversely.

2. When the ground to be built on, slopes considerably, in order that the foundation at the upper part of the building be not unnecessarily deep, and a waste of masonry be thus caused, the bottom of the excavation should be made in successive level steps descending in conformity with the slope of the ground; taking care that the bottom of the foundation never approaches too nearly the surface of the ground—thus—



Correct levels should, therefore, be taken of ground on which a building is to be erected and the requisite cuttings carefully laid down in section to scale, before a spade is put into the ground; as any mistakes made, by digging the foundation too deep in any place, must be repaired by costly masonry; any attempt to mend the matter by refilling the trench being quite inadmissible, although, unless narrowly watched, those who made the mistake will be apt to gloss it over in this manner to the imminent danger of the building to be erected.

The trench should then be commenced at its lowest extremity, and the minimum depth of foundation excavated throughout; for instance, digging it 2 feet deep at the lowest point, proceeding at this level horizontally till the bottom of the trench is 2½ feet from the surface, then rising by a step of 6 inches and proceeding as before.

In order to prevent waste of masonry, it will be best that the foundation course be of uniform height, say in the present case, $1\frac{1}{2}$ feet; on this the plinth is to be built until it shall reach the height determined on for the floor of the building, at its highest point above the ground.

When building in rainy weather, even with pucka masonry, but always when with kucha or kucha pucka, the ground to be built upon should be thoroughly drained, and earth filled in to a level with the plinth, and around it as the building advances, taking care to leave an exit for the water, at every *doorway, by omitting a couple of courses of brick under* every door sill, to be filled in with the flooring, after the roof shall have been put upon the building. The earth required for filling in the plinth or for kucha mortar, should be dug from trenches, so disposed around the building as to aid its drainage, both whilst in progress and when completed.

3. The following rules for the construction of ordinary buildings are extracted from the "Barrack Master's Assistant and Addenda," a work now out of print, but which contains much useful practical information.

"In choosing a site, particular enquiries should be made of the oldest inhabitants of the place, if any tanks have ever been upon the ground and subsequently filled up. Foundations laid upon made ground of this nature, invariably sink unless properly secured by artificial means.

"Engineers must recollect that a failure in the foundations cannot be admitted as any excuse for buildings giving way. When they have a choice of sites they should take care, by previous enquiry and trial, to select a good one; and when there may be no choice, they should take care to secure the foundation suitably, as circumstances may require.

"If it should be necessary to build on ground that has been artificially filled up, the foundation trenches must be carried down to the firm ground below, and the walls built up regularly from the bottom, or piers may be built up, at intervals, and the spaces covered by arches, the crown of which should *not appear above the level of the ground when finished.* Walls of old buildings intersecting the new should not be left, as they would prevent the new masonry from settling equally in all places.

"If the ground is sound, but very sandy, the foundation should be made very broad at bottom, and decreasing by steps to the breadth of the wall of which it is the support. If the ground is sandy at top, and good clay at a moderate distance underneath, the foundations, should be dug down to the firm earth. If, on the contrary, as often happens in the lower parts of Bengal, the soil at top is much firmer than below, it should be very little dug into.

"Even where a foundation has been dug in apparently good ground, a strong wooden beater should be used all along the trench, to detect, by sound, any hollow which may be concealed; this precaution is particularly necessary where there are many white ants. It is likewise a good precaution to pour a large quantity of water into the trench, for the same purpose.

"In sandy soils any deep excavation near the foundation, should be avoided or carefully filled up, as the weight of the building will have a great tendency to force the sand from underneath, and drive it into the hollow. When it becomes necessary to secure the foundations by artificial means, a variety of expedients should be considered, and the one best adaped to the situation, selected."

4. In all cases when the nature of the sub-soil is unknown, a trial pit should be sunk close to the site of a proposed building to such a depth as may allow the different strata to be seen; or the earth may be examined by *Boring.*

The borer is a large auger made for the purpose, having its shank composed of a great number of joints of moderate length screwing into each other, by means of which, the operation may be continued to any depth judged necessary; this instrument being occasionally pulled out of the ground by a gin and tackles, or other convenient machine, always brings up in the hollow part of the auger, a specimen of the lowest stratum of soil pierced by it; the persons employed in thus sounding for a foundation ought not to stop on finding a hard stratum such as gravel, &c., but should ascertain by boring deeper, whether the thickness of it is sufficient to ensure the safety of the proposed work.

When the trenches are dug and the bottom has been thoroughly examined and tried, should the soil prove generally firm, any looser parts, if not deep enough to render a resort to piling or building on piers necessary, should be dug up until a solid bed be got at; this portion should then be secured by ramming in small stones or pieces of vitrified brick (*jhama*), closely packed together, watered, and covered with a layer of well-ground mortar, beaten into the interstices, with a heavy rammer; if the depth is considerable, a layer of good concrete may be laid upon this, and well beaten whilst setting.

The various artificial contrivances for obtaining a firm foundation for buildings or other structures in bad soil or under water have been already treated of in Chapter XV.

The breadth usually given to foundations is one foot greater than that of the walls of the lower story, but more than this may often be necessary in Bengal, where the security of foundations in general depends on their breadth much more than on their depth; one foot, or a foot and a half, will generally be found sufficient for the latter, if care is taken that the soil underneath the foundations is protected from wet.

5. The *Plinth* should be diminished by off-sets, not exceeding 3 inches, or a quarter of a brick, on each side of the foundations, the walls of the lower story being diminished in the same manner from the plinth, and so on successively with the several stories, to the top, taking care however that the uppermost part of all be not made too weak; walls should be diminished by equal off-sets on each side, so that the centre of the uppermost course may be plumb with that of the plinth. The inner ledges, helping to carry the floors, are not seen, and those on the outer walls may be covered by a string course of stone, or an ornamental brick cornice, encompassing the whole building, which will serve to prevent the ledge from being either injurious by holding rain water, or unsightly.

When buildings of no great height are to be erected on compressible soil, and piling is not deemed expedient, hoop iron may be used to aid the bond, being built in, with good mortar, just above the first or lowest course of bricks, and may be used at every fourth course to the level of the superstructure; this will enable the walls to settle bodily, and prevent fissures.

Care should be taken in all lofty or heavy buildings, especially those with vaulted roofs, wherever openings for doors or windows are intended, to throw inverted arches between the piers. This precaution, when the building settles, will throw a proportion of the weight under the openings, and relieve the piers, by which means the cracks in doorway arches, which are so frequently seen, will be avoided.

Ranges of pillars should always have a thorough continued foundation under them, with inverted arches between the pillars; except in very slight buildings on a hard foundation, when they may be dispensed with.

The same precautions are of still more importance in the construction of arcades;—when the abutment walls of arcades with semi-circular openings are narrow, the lower part, or about 30°, of the arch may be obtained by corbelling out the abutment into the requisite form, with bricks laid horizontally and their ends cut to form the skewback from which the arch is to spring; this arrangement gives a better base to the spandril.

For ordinary buildings, arcades should be preferred to the objectionable style of construction of pillars with wooden architraves, for which flat arches may in most cases be safely substituted.

6. *Doorways* should have double arches over them, one flat or nearly so, and an upper one semi-circular, should there be space for it; if otherwise, it may be a quadrant or even a flatter segment; the flat arch is a beam of brick-work formed with bricks radiating to a centre, thus containing a segmental arch, the radius of which may be equal to the breadth of the opening. It should rise about one inch in the centre of its soffit or intrados, and its extremities should spring from a point about an inch above the top of the door frame, so that on the piers settling, no pressure should be borne by these frames or *chokuts*, which should not, however, be inserted till the roof has been covered in, and there is no fear of extensive settlement.

7. *Thickness of Walls.*—It is only when extremely heavy vaults or very high towers have to be built that the resistance to crushing need be considered in the design of a building, but it must always be remembered in such cases that allowance must be made for inexactness of bearing surface, and inequality of texture, and that at least eight times the bearing surface that would *crush* under the load must be allowed.

In architecture, walls are generally more liable to be overturned, either partially or wholly, than crushed, and the directions likely to be taken by forces having this tendency, under the influence of storms, earthquakes, &c., must be taken into consideration.

Long walls not supported by the intersection of, or the abutment on them of, other walls are evidently weaker, that is, more liable to fall from unequal settlement of their foundations, and more easily thrown down by storms or other causes than such as *are* so supported.

Rondelet, from a vast number of examples of existing buildings, deduces a rule that enclosure walls of durable materials, that is, of brick or stone cemented with good mortar, require a base varying from $\frac{1}{8}$th to $\frac{1}{12}$th of their height for lengths within the limits of ordinary construction; and taking this as a maximum, that this thickness at base may be reduced in the ratio of the cosine of the angle formed with the ground line, by a diagonal extending from the bottom of one cross wall to the top of the one next to it; or as this diagonal is to the base. In making calculations of this sort for practice, the nearest quarter or half brick above the calculated thickness should always be taken.

In treating of enclosures of a polygonal form he considers each side of the polygon as supported by the abutment of two others, but the abutment not being at right angles cannot be allowed its full effect, or a circular wall, which is a polygon of an infinite number of sides, would require no thickness. It *doubtless requires less than a wall disposed in* any other form.

8. For covered buildings, the rule given by Rondelet is, that the thickness of walls carrying a well tied roof may be $\frac{1}{12}$th of their height, under the tie-beam, multiplied by the cosine of the angle formed by the *floor, and by the diagonal drawn from the foot of one wall to the top* of the opposite one.

But if the walls supporting a roof are stiffened in any manner, such as by a lower roof at an intermediate height, as in churches with nave and aisles, his rule is to take $\frac{1}{12}$th of the height above the point stiffened, added to $\frac{1}{24}$th of the height below it, or which is the same thing $\frac{1}{24}$th of the sum of the whole height of the wall, and the height of the portion above the point stiffened.

This rule agrees with the dimensions of the church of Saint Paul outside the walls of Rome, and also with those of many other churches, measured by Rondelet. It, however, evidently should have a limit, and cannot be considered applicable to buildings whose breadth is less than half or more than twice the height of the walls supporting the roof.

And, indeed, although a well constructed roof serves to tie the walls by which it is supported together; still as all roofs are liable to deflection and derangement from changes of temperature and other causes, it does not seem advisable in ordinary practice to reduce the thickness of walls on that account, although the reduction which depends on the support given by cross walls may be made with safety.

9. Rondelet gives examples of lofty churches, in which the main walls, although supported in some cases on pillars only, have a base of barely $\frac{1}{30}$th of their height.

For instance the church of Saint Paul is 93 feet high under the tie-beams, but the supporting pillars and their superincumbent walls are but $3\frac{1}{3}$ feet thick: they are supported against falling outwards by pent-roofed aisles, but as the walls supporting the main roof are of great height and length there seems to be a liability to their bulging inwards where the pent roofs lean upon them.

The outer walls which are much lower, but which sustain the thrust of the pent roof, are considerably thicker; and the area of the whole building is to that of its points of support as 9 to 1.

In the church of Saint Paul's, London, the area is to that of the points of support as 6 to 1; in the round church of Saint Stephen at Rome, as 18 to 1; and in ordinary brick buildings in Belgium, it averages about 17 to 2.

In many vaulted buildings enormous pressure is sometimes sustained by a single pillar, but of course great care is taken in the construction of such pillar, both as to material and workmanship.

These examples are adduced to show that where both material and workmanship are good, there is little liability to crushing, and that if walls are truly plumb, and no uncompensated thrust upon them is permitted, very slight walls may safely be carried to a great height. All unequal settlements in the foundations must likewise be strictly prevented.

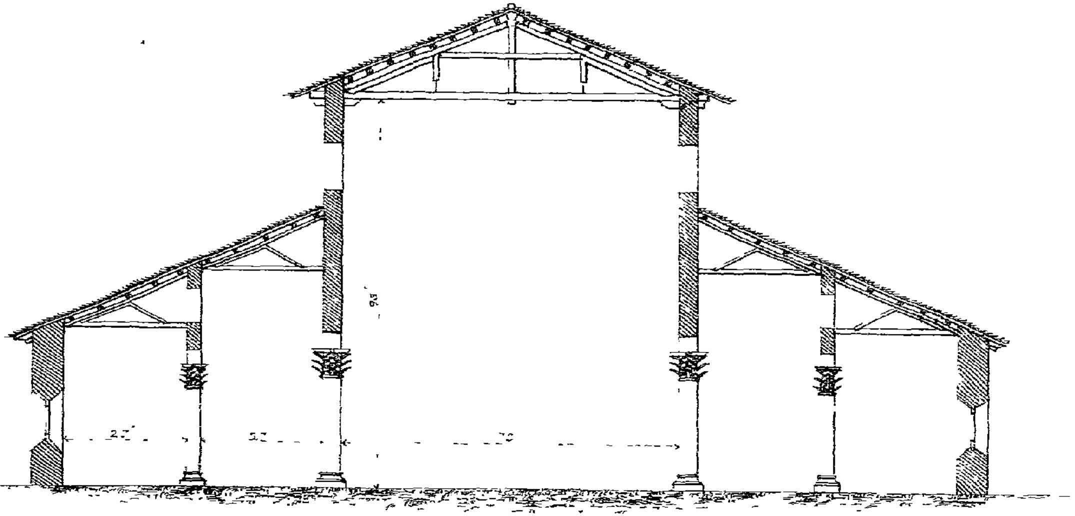
It must be remembered also that these examples are quite inapplicable to walls roughly built with bad materials, especially with such as are liable to injury by wet or other causes of decay, such as sun-dried (kucha) brick not carefully made or allowed to become wet either before or after it is built into the walls. Kucha bricks once throughly wetted never recover their consistency, but always remain friable and easy to crush.

Neither will walls of these dimensions bear untied or ill-framed roofs, which from faults of design or of workmanship do not rest on their supporting walls as a dead weight.

Rondelet gives as a rule for the thickness of the walls of dwelling houses of several stories, that the internal walls of a house without longitudinal cross walls should be $\frac{1}{24}$th part of the sum of the breadth of the house and half its height; whilst in what are called double houses, the thickness should be $\frac{1}{24}$th of half the sum of the height and breadth, which is much the same as calculating the breadth to the nearest longitudinal partition only. For the thickness of partitions, $\frac{1}{36}$th part of the sum of the breadth of the space divided by it, added to

PLATE I.

SECTION OF THE CHURCH OF ST PAUL'S, OUTSIDE THE WALLS OF ROME.



the height of the story· for instance a partition 10 feet high dividing a space of 26 feet into two portions, would require to be $\frac{26+10}{36}$ or 1 foot thick, but as this rule would make the partition walls in the lower story, carrying other partition walls above it, no thicker than those in the upper story, Rondelet allows an additional half inch for every story which the partition has to carry, so that in a six-storied house the bottom partitions would be 3 inches thicker than those at the top.

10. As Rondelet's rules give no scale for the diminution of the thickness of outer walls in each story; the following will be found to give about the same average thickness, whilst the stability is increased by giving a greater base for the wall, and placing its centre of gravity lower, which renders trifling defects of workmanship less important.

For buildings divided into stories of heights varying from 20 to 10 feet; first, take a thickness of $\frac{1}{10}$th or $\frac{1}{12}$th of the total height of the external wall, reduce it in the ratio of the base to the diagonal drawn from its top to the bottom of the opposite wall to which it is tied by roof or floor, whether this is an external or partition wall: let this be the thickness of the wall for the lowest story. Calculate the thickness of the walls of the next story in the same manner from its floor, the height being of course lessened by that of the lowest story; and so on for each story separately—taking care, however, that the walls of the highest story of all are not so thin, as to be crushed or become crippled by the weight of the roof, and some allowance must also be made for the force of the wind in storms at this height, so that a new cause of weakness being added, some allowance must be made to meet it. In ordinary cases, the thickness of the wall of the highest story may be made sufficient, by adding to it half the difference between its thickness, as found above, and that of the next story below it.

Take for instance a building 36 feet high and 24 feet wide, divided into three stories of equal height.

By the rule above given, the thickness of the walls of the lowest story will be—

$$\frac{36}{10} = 3\cdot6 \text{ then } \frac{3\cdot6\times24}{\sqrt{36^2+24^2}} = 2 \text{ feet nearly,}$$

of the middle story-

$$\frac{24}{10} = 2\cdot4 \text{ then } \frac{2\cdot4\times24}{\sqrt{24^2+24^2}} = 1\cdot7 \text{ nearly,}$$

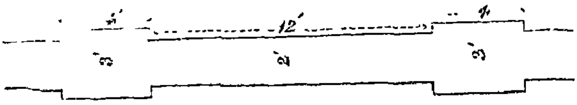
of the upper story—

$$\frac{10}{12} = 1{\cdot}2 \text{ then } \frac{1{\cdot}2 \times 24}{\sqrt{12^2+21^2}} = 1{\cdot}1 \text{ nearly,}$$

or allowing for weight of roof $\frac{1{\cdot}1+1{\cdot}7}{2} = 1{\cdot}4.$

And using bricks 12 × 6 inches the walls would, taking the nearest quarter of a brick greater than the calculated dimension, be 2 feet, 1¾ feet, and 1½ feet thick.

11. Walls are also much stiffened by having a proportion of their average thickness disposed in the form of buttresses; about one-eighth seems to be a good proportion as in the following diagram:



$4 \times 3 + 12 \times 2 = 16 \times 2\frac{1}{4}$ the average thickness.

And this arrangment is particularly *applicable to enclosure walls*—which are likewise much improved in appearance thereby.

In house or other architecture, pilasters and panelling may be used to produce the effect contemplated, which is, with an equal quantity of materials to obtain an enlarged breadth of base. Italian towers or campaniles are built in this manner with excellent effect, both in an *architectural and in an engineering point of view.*

12. *Arches* in brick-work are plain or rough, cut or gauged. Plain arches are built of uncut bricks, and the bricks, being rectangular in section, while that of the arch is wedge-shaped, the inner or lower angles of the uncut bricks should be in contact, and the wedge-shaped voids between them must be filled with mortar: if the arch is of so small a radius as to leave large voids, broken brick may be mixed up with the mortar used in filling these interstices; mortar for arches should be more carefully made, and thoroughly ground than that required in ordinary walling. In consequence of this inherent defect in uncut brick arches in extensive continuous works, such as sewers, tunnels, vaults, &c., it is advisable to make them in thin independent rings of half-brick or one brick thick, as the case may be; that is, a one foot arch should be in two half-brick arches, and a one and a half foot arch in three half-brick arches. *It is evident that,* by this mode of construction, a greater quantity of the solid material comes into the back or outer ring of the arch than into the lower one; and if they had been bonded together into one arch, all that difference must have been made up with mortar.

Gauged arches are composed of bricks which are cut and rubbed to gauges and moulds, so as to form perfectly fitting parts in the arch. Gauging is not only applicable to arches, as it means no more than the bringing every brick exactly to a certain form, by cutting and rubbing, or grinding it to a certain gauge or measure, so that it will exactly fit into its place, as in the finer works of masonry.

13. *Wall-plates* are required to receive the ends of all joists, so as to distribute the weight of the floor or roof to which they belong, equally along the walls. If the joists rested singly on the naked bricks, their thin edges would crush those immediately under them. Lintels are sometimes used over square-headed windows and doors, instead of arches in brick-work, when required to preserve the square form and receive the joiner's fittings, but they should always have discharging arches over them, and should not tail into the wall at either end more than a few inches, in order that the discharging arch may not be wider than is absolutely necessary. If, however, discharging arches be not turned over them, the lintels should tail in at each end considerably, and have templates or wood-bricks running right through the wall placed transversely under them. Flat arches should, however wherever possible, be preferred to lintels. Discharging arches should be turned over the ends of beams. They may generally be quadrants of a circle, or even flatter, and should be turned in two or more half-bricks over doors and windows, and other wide openings, but over the ends of beams they need not be more than a half-brick thick.

14. *Wooden bricks* are used to prevent the necessity of driving wedges into the joints of brickwork to nail the joiner's work to. They are pieces of timber generally cut to the size and shape of a brick, and worked in as bricks in the inner face of a wall, where it is known that the joiners will have occasion for something of the kind. Punkahs, and the requisite arrangements for pulling them, wall shades, accoutrement pegs, shelves, and all fittings should be carefully provided for in the working plans of all buildings requiring them.

15. *Chimneys.*—Not the least important part of the bricklayer's art is the formation of chimney and other flues. Chimney flues are plastered or pargetted with a mortar in which a certain proportion of cowdung is mixed, which prevents it from cracking and peeling off with the heat to which it is exposed. Experiment has proved that a tapering and nearly cylindrical flue of a small bore is the best for carrying away smoke. Of course, too, the bore should be regulated by the size of the fire-place, or rather by the quantity of smoke to which it is required to give vent. In laying out the fire-place all the lines should converge towards the throat of the chimney, which should be contracted, and immediately over the fire, because as soon as the sides of the throat are heated, air begins to ascend through it. The flue should widen out again above this contraction.

Plastering has been already treated of in Arts. 103 and 228, *et seq.*, and the *Coloring* of *Walls* in Art. 111, Vol. I.

CHAPTER XXV.

FLOORS.

16. *Brick-on-edge Floors.*—These should be very carefully made. In the first place the ground should be truly levelled, (or, if the floor is intended to have a slope, made parallel to it,) and thoroughly consolidated by being well rammed. On the surface so prepared, which should be 1 foot 3 inches below the intended level of the floor, a layer of dry sand 3 inches deep must be spread, as a preventive against damp and white ants; on this two courses of bricks are laid flat, and set in mortar; this will leave 6 inches for the uppermost, or brick-on-edge, course. The best shaped and burnt bricks should be picked for this course; their surfaces which are to be placed in contact should be rubbed perfectly smooth so that they may be laid quite close to each other, with merely a thin joint of the finest cement between them which should be thoroughly well ground; care should be taken that the workmen covers the side of the brick last placed with mortar before he places the next one against it. When finished the joints should be carefully filled in with a little chunam and water. When the floor is not required to be very solid, one of the courses of brick flat is omitted. The bricks-on-edge are usually laid in parallel rows, breaking joint, but sometimes in herring-bone bond.

The practice of covering brick-on-edge floors with a thin coating of terrace is objectionable; it seldom is of sufficient substance to be lasting, and native workmen are, chiefly desirous of using it for the purpose of concealing coarse work. If the floors be made as above directed no terrace can be required.

For brick-on-edge floors, small bricks have been recommended, but if large bricks be used there will be fewer joints between them, and 12-inch bricks may be very well burnt if proper care be taken.

17. The above description of floor is recommended for Store rooms or *godowns*, on which heavy weights are likely to be placed, but for cutcherries, jails, hospitals, cook-rooms, &c., &c., substantial *Paving Tiles* 15 or 18 inches square, and 2 or 2½ inches thick are considered preferable.

When paving tiles are used for floors they should be correctly squared, and their edges trimmed, that they may be laid with precision and their joints made as fine as possible. They are laid on the same foundation as the bricks-on-edge, and afterwards neatly pointed with the strongest cement. Their surface of course must not be rubbed, as it would destroy the glazing of the tiles.

When *Flag Stones* are procurable, they are, in many cases, to be preferred to any of the above descriptions of floor, as being more durable and less easily injured; but care should be taken to avoid those descriptions of stone which imbibe and retain moisture. They are laid in the same manner as tiles.

18. *Terraced Floors* depend for their excellence on the goodness of the mortar, and the care taken in beating it. The process in the Upper Provinces is as follows:—First, the ground is prepared and sand laid as with the other kinds of floors; then kunkur or broken brick with a little thin mortar poured over it, and well beaten; then a layer of a good building mortar of fresh kunkur, lime and bujree, or of stone lime and soorkhee, to be kept thoroughly wet, and well beaten by light hand mallets (*thappees*), till the mortar is set; the soorkhee mortar will require most labor. If the mortar has been well ground, one layer of 4 inches thick, beaten down to 3 inches will suffice. This process of beating will bring a large proportion of lime and the other finer particles of the mortar to the surface, which, when the beating has been carried far enough, may then be rubbed smooth; and before it is allowed to dry completely the surface may be enamelled with fine lime, laid on with a brush and polished with a trowel. The greatest care must be taken to allow no part of the work to dry from its commencement till it is finished, especial care being taken at the joining of different day's work to blend them so thoroughly that the lines of juncture shall not be discoverable; covering the work with a thick layer of wet sand as soon as the surface is set, is a good plan to keep it moist.

This is the practice in the N. W. Provinces. In Bengal, however, the method is different. There the terrace is not composed of mortar, but of brick broken to small pieces so as to pass through a 3-inch ring. This is spread 6 inches thick, on a single course of bricks laid flat immediately over the sand, and mixed with a certain proportion of dry lime; when this has been thoroughly mixed, water is added, and the whole raked up and turned over by men with phourahs; the surface is then carefully levelled off to the correct slope with long straight edges, and then the whole is beaten with mallets till it is reduced to two-thirds its original thickness, and the surface becomes nearly smooth; when a layer of mortar three-eighths of an inch thick is laid on and also beaten. The surface is finished off by a *very* thin layer of lime laid on moist, and well rubbed in with a good deal of pressure. It is of the greatest importance that the whole work be kept moist until complete, and when finished, be covered with matting or otherwise protected from the sun, and occasionally moistened so as to prevent its drying too quickly.

Terraced floors though very common and well adapted for private houses, are not suitable for public buildings, as they soon get broken from the wearing of feet, and are very difficult to repair. A brick floor is in every way to be preferred for such buildings.

19. It is greatly to be regretted that a systematic attempt has not been made to introduce the manufacture of *Colored Tiles* into this country, so admirably adapted for floors of all sorts, from the plain colors which are suited for Churches, Barracks, Court-houses, &c., to the beautiful encaustic patterns which would answer so well for private houses.

Glazed Tiles of several colors are however made at Mooltan, Delhi, and a few other places, which are used for Halls, Churches, Verandahs, &c., but the glaze is objectionable as apt to chip off and as being too slippery.

20. In a damp climate, such as Bengal, where special precautions are requisite to prevent moisture from rising out of the ground, *Flues* are sometimes formed under the floors by means of walls from 9 to 12 inches apart, and of about the same height and thickness; these flues should be well plastered throughout, and built of the hardest brick procurable. Their ends should also be carefully closed by iron gratings to prevent their being inhabited by vermin.

Hollow earthen pots or drain tiles may also be used under the floors, but if salts are present, their crystallization will soon destroy the pottery.

21. *Asphalte*, or rather asphaltic cement, makes an excellent floor; the best is that in which the limestone is found impregnated naturally with bitumen, and is in England called Seyssel asphalte, from the place where that first imported into England was quarried; the proportion in it of calcareous matter to bitumen is as 83 to 17, and the amalgamation is more perfect than in the cement composed of bitumen and chalk or powdered lime stone, made in imitation of it.

In using the natural asphaltic cement, it must be ground to a fine powder, sifted, then mixed with about one-fifth of its weight of pure bitumen, and heated in an iron boiler, taking care to stir it well the while.—when thoroughly mixed and of a proper consistency, it is ladled out with an iron spoon, and is spread on the floor, of the thickness required, in rectangular iron moulds (which should be as thin as possible consistent with strength) without bottoms. These moulds having been previously smeared over with a thin paste of loam, are then removed and the process repeated by placing them close alongside of their former position. The narrow joints left must be filled with hot composition, pressed in and smoothed over with a hot soldering iron. Ure states that boiled coal tar, and thoroughly dried limestone, chalk, or even brick-dust in powder answers equally well, but it may be doubted whether, though probably efficient and almost everywhere procurable at a much lower cost, any freshly made compositions can equal the natural cement in resisting alteration from extremes of heat and cold.

The natural cement has likewise the advantage of being less inflammable, in consequence of the bitumen being more thoroughly amalgamated with the uninflammable basis of the composition than in the factitious cement. London, in his Encyclopædia of Cottage Architecture, gives the following recipe.—Take 18 parts mineral pitch, 18 parts resin, put them into an iron pot to boil, taking care that it does not burn; then stir in 60 parts of sand, 30 of small gravel, and 6 of slaked lime. These materials should be thoroughly dry. Two inches is a sufficient thickness for ordinary floors.

22. The composition used in this country by Professor O'Shaughnessy for the protection of telegraphic rods, laid under ground, consists of 120 parts (by weight) of pure resin (American) and 300 sand; it has been recommended for the lining of cisterns, and other building purposes, and the following is Dr. O'Shaughnessy's description of the manner of using it for coating floors, cisterns, &c.

The resin is melted in an iron vessel, the sand stirred in and well incorporated with an iron stirrer, and the whole poured when of the consistence of treacle. Great care must be taken to prevent the resin from taking fire, or charring by too prolonged or too high a heat.

The cement thus prepared may be cast into bricks or tiles, or poured on floors or roofs or on planked flooring, to all of which it firmly adheres. Joints are readily and securely made by pouring a little melted resin or pitch into the line of juxtaposition of the bricks or tiles, and cracks are filled up in the same simple way.

A tile of this kind 12 inches square and 1½ inches thick, weighs 387 tolas. If carefully prepared, this cement is totally impermeable to water, and is not affected by the fiercest solar heat. It withstands dead pressure better than common bricks or tiles.

The composition is brittle, so that for roofing or flooring purposes, it is very much improved by slips of bamboo being inserted in it while soft. A very coarse Durmah mat placed on its surface while still soft is a great improvement to it for flooring purposes, and if used in a thoroughfare, a thin layer of sand or road dust laid over it while hot will be found to preserve the surface from abrasion. It need scarcely be pointed out, that notwithstanding the unquestionable and remarkable advantages derivable from the use of this cement, it is open to the very serious objection of being dangerous in cases of fire.

The ordinary cost of resin is Rs. 2 per maund. At this rate, not including the slight cost of fuel for melting, and the labor of preparation, this cement cost Rs. 7-8 per 100 superficial feet of 1½ inches thick, and price of sand not included, would cost Rs. 0-7-7 per maund of 80 pounds avoirdupois weight.

23. In the greater part of India timber is so expensive and so many causes are at work to destroy it that *Wooden Floors*, so common in England, are rarely used, except in the Hill stations. In houses of more than one storey they are however almost indispensable for all but the rooms on the ground floor. The planks are nailed to joists which rest on timbers stretching from wall to wall, which are secured to wall plates in the masonry, as in the case of a flat roof.

CHAPTER XXVI.

ROOFING.—FINISHING.

THE Construction of the flat or sloping timber supports commonly used for roofs having been already treated of under the Section CARPENTRY, it remains to give further details of the *Roof Coverings* employed, and to add some account of the *Iron Roofs* which are now so extensively used both in India and England.

24. The coverings of flat roofs are various. In the Punjab, one of the most usual consists of a course of bricks or flat tiles, or slabs of stone, united by lime mortar completely closing all the seams, and above the bricks a layer of earth, 3 to 6 inches thick, well beaten down. This makes a good roof; but to ensure its being so, the earth must be both prepared and applied with much care. As for brick-making, so also for roofing, it must not be a hard stiff clay, which soon cracks in the sun's heat, nor a loose sandy soil which rain will readily penetrate. A good brick-earth makes a good roof covering. Such roofs require frequent beating to consolidate the layer of earth. This is termed a *Kucha-Terrace* roof.

As a bed for the covering of earth, a layer of the reeds, called *surkunda*, laid down over the horizontal rafters in small bundles tightly bound and closely packed, may be used instead of bricks. This is a convenient and economical method, the material itself being cheap, the wood also not requiring to be laid so close as for bricks; and where the clay is good, and the roof not liable to be attacked by white ants, it is found to answer well. The small twigs of a common jungle shrub, called *sambháloo* or *samáloo*, are successfully employed as a substitute for surkunda, and there are many other straight branched shrubs and trees, as *jháo* (tamarisk), and such like, which may be similarly used.

25. To get rid of the chances of failure from the use of unsuitable soil, as well as to avoid the unsightly defacement of the outer walls caused by the discharge of muddy water from the roof after rain, the earth is often dispensed with, and the whole upper surface of the roof plastered. The prevention of leakage may be further secured and the coolness of the building promoted (at the expense of additional weight upon the beams) by a second course of the bricks or tiles laid over the joints of the lower course. This roof is known as a *Pucka Terrace roof* and its construction is very similar to that of the terraced floor. The room to be roofed having been covered with beams, of size and interval between them calculated for the weight to be borne, these are again covered at right angles by small joists or battens, called *burgahs,* usually about 3 × 3 inches in section. They are laid 12 inches apart from centre to centre, so that the bricks laid across them, to form the substratum of the terrace floor, may just butt against each other. Where flat tiles about 1 foot square and from 1 inch to 1½ inch thick can be obtained, they are preferable to bricks, but two layers of them must be used, the first laid square across the burgahs and the upper set breaking joint with them diagonally or otherwise, and with a thin joint of good mortar between them. The terrace is then laid over this in the same manner as in terraced floors, particular care being taken that sufficient slope is given to the surface to carry off rain water quickly. This is generally done by an additional thickness of terrace at the centre, to avoid the unsightly appearance that beams laid with a slope would have from the interior, but in godowns, barracks, &c., where appearance is not of such consequence, the requisite slope should be given to the beams and the terrace be made the same thickness all over. At the junction of the roof-covering with the wall, the terrace should be lapped over the upper surface of the latter at least 6 inches : the parapet being carried up afterwards if necessary, on the top of this.

Three layers of tiles laid to break joint, the upper layer being covered with a thin coat of plaster, well polished and oiled, forms a very durable flat roof, and possesses the advantages of being more quickly made and lighter than a terrace-roof.

The following is a receipt issued by Captain Glover, to officers on the Western Jumna Canals, for filling up cracks in pucka roofs to which they are very liable. Linseed oil *(ulsêe ka tel)*, 2 seers. Resin *(dhúna* or *rál*), 2 seers. Pumice stone *(jháma)*, 1 seer. " Boil the oil, and then, having first pounded it very fine, mix the resin well with it, and last of all the pumice stone, also pounded very fine. The cracks should not be disturbed or dug out with the trowel, but the liquid mixture poured in and then merely smoothed over the surface."

26. To overcome the difficulty of obtaining timbers for roofs of a large span in this country, many substitutes have been tried, such as the Syrian and Sind tiled roofs, described in Chap. XIV.

A new kind of roofing has also lately been introduced, which appears well adapted for ordinary building purposes. This consists merely of an *Arch* of one ring of brickwork, starting from two metal or wooden wall-plates or skew-backs built into the wall, the outward thrust being met by iron tie-rods running from wall to wall, and securely fastened into the wall plates. Mr. W. Clark, Engineer to the Calcutta Municipal Commissioners, the patentee of this invention, has roofed a workshop of 40 feet span in this manner, with an arch of 6½ feet rise, tied by double rods 1 inch in diameter and 7 feet 9 inches apart, at a cost of 12 annas per square foot. His wall plate he forms of two strips of boiler plate iron arranged thus ⊢, one vertically and one horizontally; the vertical one being on the inner side; built into the wall so as to prevent their buckling. "The ends of the tie-rods are formed into loops into which the horizontal plates are passed: the tie-rods pass through holes made in the vertical plate; against the latter the bricks are placed on end,* and the skewback is so arranged as to bring the centre of the thrust on the edge of the horizontal plate, through which it is communicated to the tie-rods." In places where iron plate is not obtainable the tie-rods might be bolted through an ordinary timber wall-plate, or through a solid stone, as has been done where that material is plentiful. By filling in the haunches above the arch, floors may be made on this principle. *Arched Roofs*, with or without iron ties, have been largely used in the East India Railway Stations, and other buildings in Northern India. They are durable and water-tight, but are said to be hot.

27. Sloping or pitched roofs are generally covered with thatch or tiles, in this country. For *Tiles*, a slope of about 27° is recommended. Whatever description of tiles be used they should be bedded in mortar or cement. A layer of flat tiles underneath the ordinary tiles of the country will generally be found to ensure a water-tight and comparatively cool roof, but it of course adds much to the weight. In all tiled roofs the eaves require to be very carefully and strongly constructed, as the displacement of the eave

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* See *Calcutta Engineer's Journal*, Aug. 3rd and November 18th, 1859, and 1st October, 1861.

tiles is otherwise a constant source of trouble and expense. Tiled roofs should be protected by gable-ends to prevent wind getting underneath and shaking the tiles.

28. *Goodwyn's Tiled Roofing* has already been partially described in para. 30, Vol. I., where a drawing is given of that construction. The following additional details are taken from a report by the late Captain Sharp, Exec. Engineer, Mean Meer.

Deodar battens, 3 × 2 inches are nailed on the purlins at twelve inches from centre to centre, on which are laid twelve-inch square tiles, two inches thick, well fitted, cemented at the joints, and pointed underneath; a layer of good mortar about one and a half inches thick is then laid, in which the pan-tiles are well embedded at regulated intervals, which are filled up with mortar, and over them the round tiles carefully fitted and set. The eaves terminate in a masonry cornice, as shown in the figure, and the ridges are covered in with round and flat tiles, expressly made for the purpose; gable ends have been adopted as better suited to this description of tiling; the slope of the roof 28°. After the tiles had been laid the joints were carefully pointed, and the roofing kept well wetted during its construction, and for ten days afterwards, by means of watering pots used from the ridge of the building, not in a stream down the roof, but merely sufficient to keep the whole saturated.

(1) WEIGHT OF TILING PER SQUARE FOOT.

		lbs.
One square tile, 12 × 12 × 2 inches,	– – –	19
One pan-tile,	– – – – –	6
One round tile,	– – – – –	4
One and a half inch of mortar,	– – – –	12
Total,	–	41

(2) DETAIL OF LABOR AND MATERIALS PER 100 SQUARE FEET.

	Labor.			R.	A.	P.
½	Mate mason,	@ As.	5	0	2	6
10	Masons,	„	4	2	8	0
⅓	Grammie,	„	2½	0	0	10
2	Bheesties,	„	2½	0	5	0
¼	Carpenter,	„	4	0	1	0
½	Mate coolie,	„	2½	0	1	4
14	Coolies,	„	2	1	12	0
1	Coolie,	„	1½	0	1	6
	Establishment,			0	2	6
			Total Rs.,	5	2	7

	Materials.		R.	A.	P.
100	Square tiles,	@ Rs. 25 –	2	8	0
110	Pan-tiles,	} „ 15 –	3	4	0
110	Round tiles,	}			
25	Maunds of kunkur lime, @ Rs. 15 per 100,	–	3	12	0
2½	Stone lime, @ Rs. 1,	–	2	8	0
	Scaffolding, &c.,	–	0	6	0
	Total Rs.,	–	12	10	0

29. *Atkinson's Tiled Roofing.*—Atkinson's pattern consists of two layers of tiles, the upper being Italian pantiles, laid in cement over cylindrical tiles

(*a.*) The cylindrical tiles to be 12 inches long, 4 inches external diameter, and half inch thick, fitting one-half inch into each other, with a shoulder and socket joint; a lip, to rest on the timbering, to be raised on at half an inch from the shoulder, two holes of half inch diameter each, to be pierced through the tile in line with the lip which is on the lower side of the tile.

(*b.*) These cylindrical tiles being laid close, with their axes up the slope of the roof, are to be covered with coarse mortar or fine concrete to a depth of one inch, and in this, while still wet, will be laid Italian pantiles.

(*c.*) The pantiles are to be 12 inches long and 12 inches wide over all, and not less than half an inch thick.

(*d.*) The mortar in which the tiles are laid is to be drawn up, so as to fill the curved roll which overlaps at the vertical joint.

(*e.*) The lower edge of each pantile to overlap 3 inches the tile below it. A lip to be raised on the under side of each tile to rest against the lower tile and prevent slipping.

30. Of all roofs a good *Thatch* is the coolest and driest. In England, thatch is made of unthreshed straw or occasionally of reeds; in this country of long grass* laid on a frame work (*jáfari*) of small bamboos placed over the wood-work of the roof. This jáfari is made on the ground, of whole bamboos laid in a lattice form like trellis-work, with intervals of about 6 inches, over which split bamboos are fastened about 2 inches apart, the whole being tightly secured with string. Over this jáfari is laid the grass in layers 3 inches in thickness; the first layer being generally attached before the jáfari is placed on the roof.

Thatch ought to be at least 9 inches thick and varies from 6 to 12 inches, requiring a fresh coat of 3 or 4 inches in thickness every three years. The grass is bought in bundles called *poolas*† which are broken up

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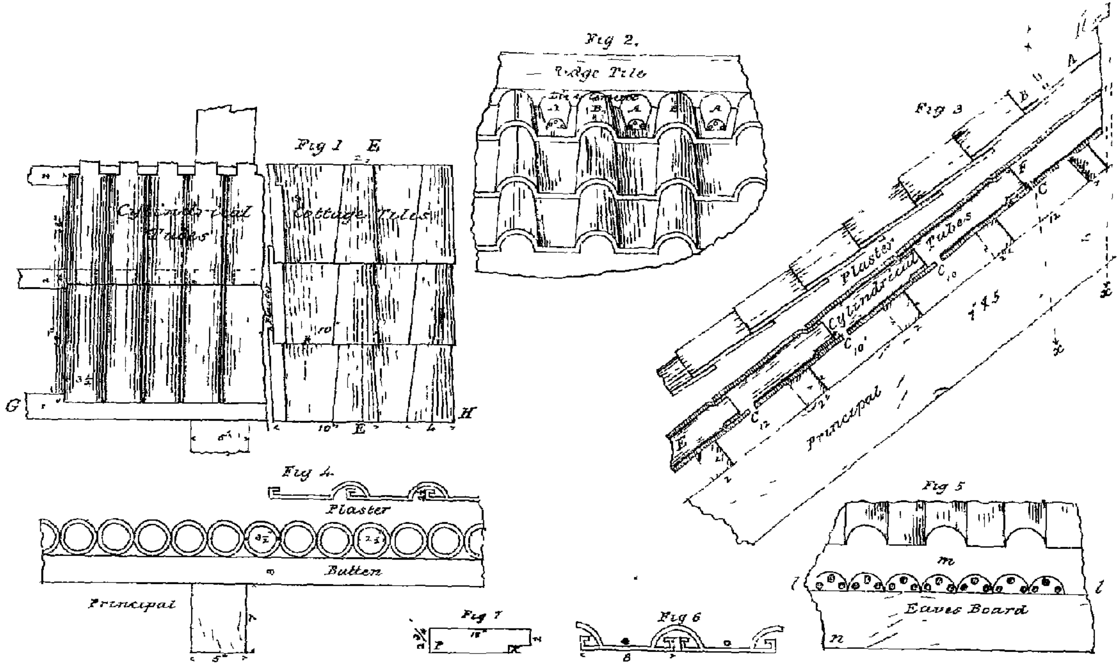
* The best grass is that which bends easily without breaking, being wiry and flexible.

† A *poola* is a bundle generally about 5 inches in thickness, tightly bound, but there does not seem to be any very definite measure of its bulk. It is said to be as much as can be grasped by the two hands, separately, and weighs from eight to twelve chittacks, but the *poola* varies so much in different districts that it is well to purchase it by the 100 superficial feet, so many inches thick. Of such poolas, about 320 are required for each 100 feet.

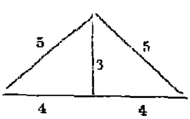
ATKINSON'S TILED ROOFING.



T C PRESS

and spread flat between two pieces of split bamboo. The thicker or lower ends of the grass are dressed evenly to one line, and the grass in its position on the roof lies with these ends towards the eaves. These bundles are then fastened to the bamboo frame-work, beginning from the eaves upwards; and so overlapping each other that the small pieces of bamboo which keep them in position are not seen from the outside. All along the eaves, larger but round bundles of grass are placed, the full thickness of the thatch. These like the others have their thicker ends downward, and are packed as tightly as possible. The ridge of a thatched roof is generally bound with a roll of sirkee laid horizontally. The same is occasionally done under the eaves.

For thatched roofs, a *pitch* or inclination of 35° is recommended, but that obtained by making the rise in the centre three-quarters of the half breadth of the building, is found to answer well. This rule is further convenient as it facilitates the calculation of the superficial area of the roof; the breadth of the sloping side—the hypothenuse of the right-angled triangle—being then five-fourths of the same base or half breadth of the building, with the addition of whatever projection of eaves may be desired.



The following Specification for Thatched Roofing, as used in the Allahabad Circle of Public Works, may be found useful:—

Grassing.—The several descriptions of grass roofs are to be well and closely tied, laid in one, two, or three layers according to circumstances, and in such manner as the Executive Engineer may direct.

The quantity of grass, bamboos, and string to be used will in a measure depend on the description of each procurable in the market.

Grass bundles of the ordinary size of Gurrur grass, from 100 to 150 bundles per inch of thickness, per 100 superficial feet of roofing, will be required, and about 25 bamboos (ordinary Pillibheet) and 3½ seers string *(ban)* to each layer of the coating.

The grassing of a roof will not be considered properly executed if it sink more than one-eighth of its thickness with the weight of a man standing on it.

Where the thickness of grassing is to exceed 8 inches when finished, it will be laid on in three layers. The first not exceeding one-third of the whole thickness may, if ordered by the Executive Engineer, be of *surput* or *khassa*, or other reed or coarse grass, and it may be, in the first instance, laid loose on the roof and tied tightly down with battens not more than 9 inches asunder, the ties at not greater intervals than 9 inches. The second and third coats to be always of Gurrur grass made up into tatties on the ground; each of thickness sufficient to form one-third of the finished coating, the grass closely packed and tied with two battens below and two above, with ties at intervals not greater than 18 inches, each layer of tatties to be separately laid and tied on to the roof with ties at not greater intervals than 9 inches. The whole surface of the finished roof to lie evenly without rises or hollows.

Where the thickness of grassing is to be less than 8 inches, it may be laid on in two layers; both will be of Gurrur grass laid as specified for the upper two layers above.

The [illegible] are to be of the full thickness of the grass coating, evenly and tightly laid, cut off squarely and neatly and perfectly straight.

Where the renewal of top coat has to be executed, the old top coat will be entirely removed. All hollows will be made up evenly with fresh grass laid under the battens of the lower coat, to which new ties wherever required will be given, and the top coat of new grass will then be laid on as above.

31. Tiles are sometimes laid over thatch. If *very carefully* done, and the layer of thatch be thin, it may answer, but experience is much against the combination; the thatch decays, the tiles subside, and the roof ceases to answer its purposes. It protects the thatch from fire somewhat, whilst the thatch so long as it is good, ensures the tightness of the roof, a difficulty with tiles.

32. A *terrace roof* may also be laid over a truss as well as over flat beams, when the pitch is not too great. Purlins about 4 × 3 inches may be laid from rafter to rafter, at 1 foot apart, or they may be laid at intervals of 3 feet with a greater scantling, so as to support battens 12 inches asunder. In either case square tiles (12 inches square and $1\frac{1}{2}$ inch thick are laid in cement on the woodwork, as in the case of Goodwyn's tiled roofs), and 3 inches of plaster well beaten may be laid over them instead of the round tiles. This makes a light and durable roof, but it is hot and apt to leak.

Lead and *Zinc* in sheets are sometimes employed as a covering for roofs. The lead weighs from four to eight pounds, and the zinc from twelve to twenty ounces, per superficial foot. *Slate* is also in use to some extent as a roofing material in the hills.

33. *Planking*, with tarred seams, is a very common roof covering in the Himalayan hill stations. It requires to be made in the most careful manner, and of the most thoroughly seasoned wood, being exposed to very trying alternations of temperature, as well as of dryness and moisture, and exceedingly liable accordingly to warp and crack; the inconveniences of which only become known when the rainy season sets in, or when the roof is covered with snow, at which times repairs are not easily effected. The planking is sometimes covered with sheet-iron, but corrugated sheet-iron, galvanized, might well be substituted and is daily coming into use in India especially for coverings for godowns, open sheds, &c.

34. *Shingles*, which are rectangular pieces of plank applied in the same manner as slates, are likewise much employed in the hills for roofing. English deal packing cases, beer chests, &c., are not uncommonly cut up for this purpose, the wood being well seasoned, and the boxes seldom fit for other uses.

Another material used for the roof covering of hill-houses is the composition called *Oropholite*. It is made of sharp river or pit sand and chalk, with a admixture of litharge, all finely sifted and made into a paste with linseed oil. This is spread on one or both sides of any kind of common coarse cloth, so as to form when dry, a sheet about three-eighths of an inch thick. The sheets when prepared are hung up to dry, and are then applied in pieces of such size as may be found convenient.

35. *Iron Roofs.*—Under the section CARPENTRY, various trusses were described of iron and timber combined. It remains to say something of Iron Roofs, as that material is now so much employed both for the trusses and the roof covering.

Iron Girders may be used in place of beams to carry flat roofs; and they may be of cast or wrought-iron, though the latter are now almost universally employed as lighter and not liable to break suddenly, though more expensive. They are usually made of this shape I, the upper and lower flanges and web being composed of one or more thicknesses of *boiler plate*, strengthened at the corners by *angle* iron, the whole connected by rivets. Of the strength of such girders and their requisite section to bear a given load, something has already been said in Arts. 196, *et seq.*, and more will be said further on when we treat of the application of Girders to BRIDGES. The formulæ in Art. 198, may be used in calculating their strength, or the following, which is more generally useful, $S = \frac{WL}{8D}$ where

S = sectional strain on centre of upper or lower flange in tons.

L = clear span of girder in feet.

W = uniformly distributed weight to be supported.

D = depth of girder in feet.

The safe maximum strain on the flanges is usually taken at 5 tons per square inch for wrought-iron, and the depth is generally made *one-twelfth* of the clear span. So that for any given load and span, the requisite sectional area of iron may be readily ascertained.

For estimating the *weight* of such girders the practical rule is—*Ten times the sectional area in inches gives the weight in lbs. per lineal yard.*

When large spans are to be covered in, the girders may be made tubular as in the case of bridges.

The superstructure of girder roofs is various. Smaller cross-girders or wooden beams may be used, to carry square bricks and a layer of beaten terrace as already described. Or small brick arches may be turned between the girders; this is a kind of roof that has lately been much employed in Upper India as very strong and durable.

36. Sections of some roof girders lately made at the Roorkee Workshops, are shown in the annexed Plate.

No. 1. Shows girders for a roof 20 feet and 15 feet span; the number required for a room 20 × 20 feet is two, with four tie-rods, and four washer plates; and the total cost Rs. 215, or Rs. 0-8-9 per square foot. For a room 15 × 20 feet, the same number of girders and ties would be required; the cost would be Rs. 120, or Rs. 0-6-5 per square foot.

No. 2. Shows girders for a room 22 feet span, three girders and tie-rods are requisite for a room 22 × 22 feet, and cost Rs. 331, or Rs. 0-11-0¾ per square foot. The verandah girders are placed 6 feet apart, and cost per square foot of room covered Rs. 0-9-6 The girders in drawings, Nos. 1 and 2, are intended to have brick arches between them, springing from the lower flanges

No. 3. Is fully explained by the different sections shown, the top flange supports a heavy brick arch, and to the bottom flange a ceiling of 3-inch sal planking is attached. The total cost is Rs. 7,000, or Rs. 2-10-5 per square foot.

37. Iron Trusses are usually made of single or double angle-iron, the various parts being bolted together and rod-iron being often substituted in the suspending pieces. Purlins of angle-iron or timber purlins are usually bolted to the rafters, on which a covering of Tiles, Terrace, &c., may be laid in the usual manner. Corrugated Iron is also much employed in such roofs, but it is too hot for buildings unless laid over some good non-conductor of heat, such as planking or felt, and both these are perishable; for stores, workshops, &c., it is however excellent.

The strength of the several parts of an iron truss may be calculated in the same way as has already been explained for wooden trusses, using of course the proper co-efficients for iron whether in compression or tension.

38. Some drawings are here given of Trusses lately made up in the Roorkee Workshops.

No. 4. Shows a corrugated galvanized iron roof on wrought-iron principals, the area of the room that it covers is 1,260 square feet, and the cost fixed, Rs. 1,260, or 1 rupee per square foot.

IRON ROOFING.

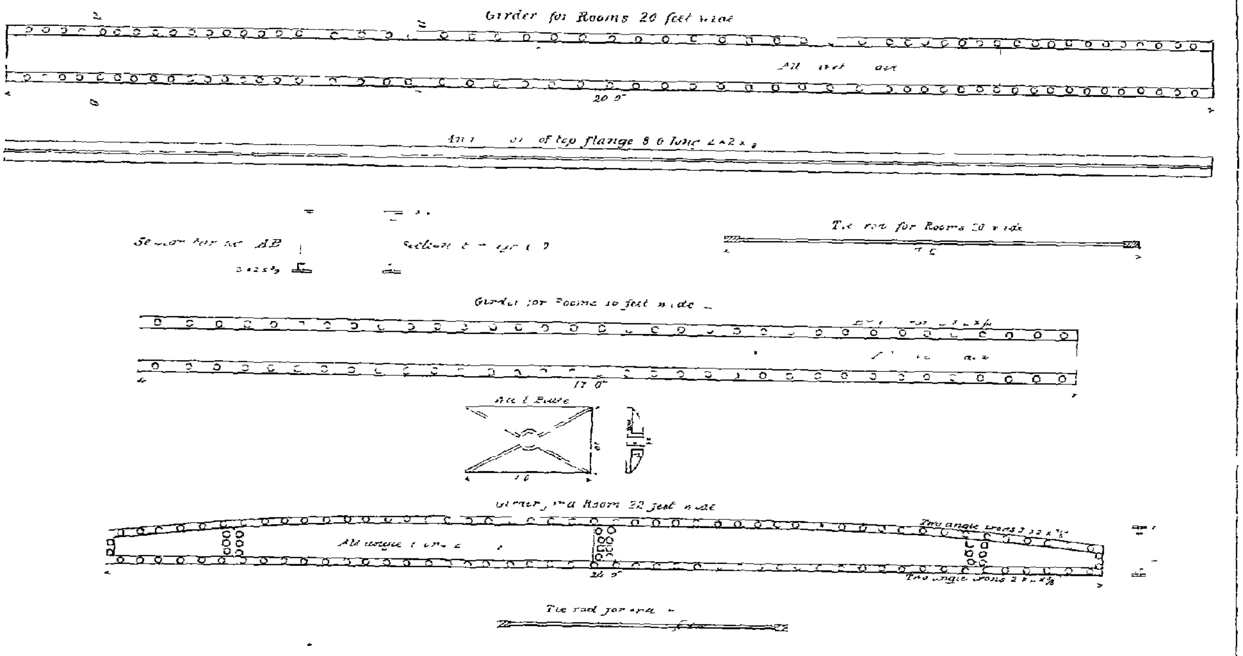
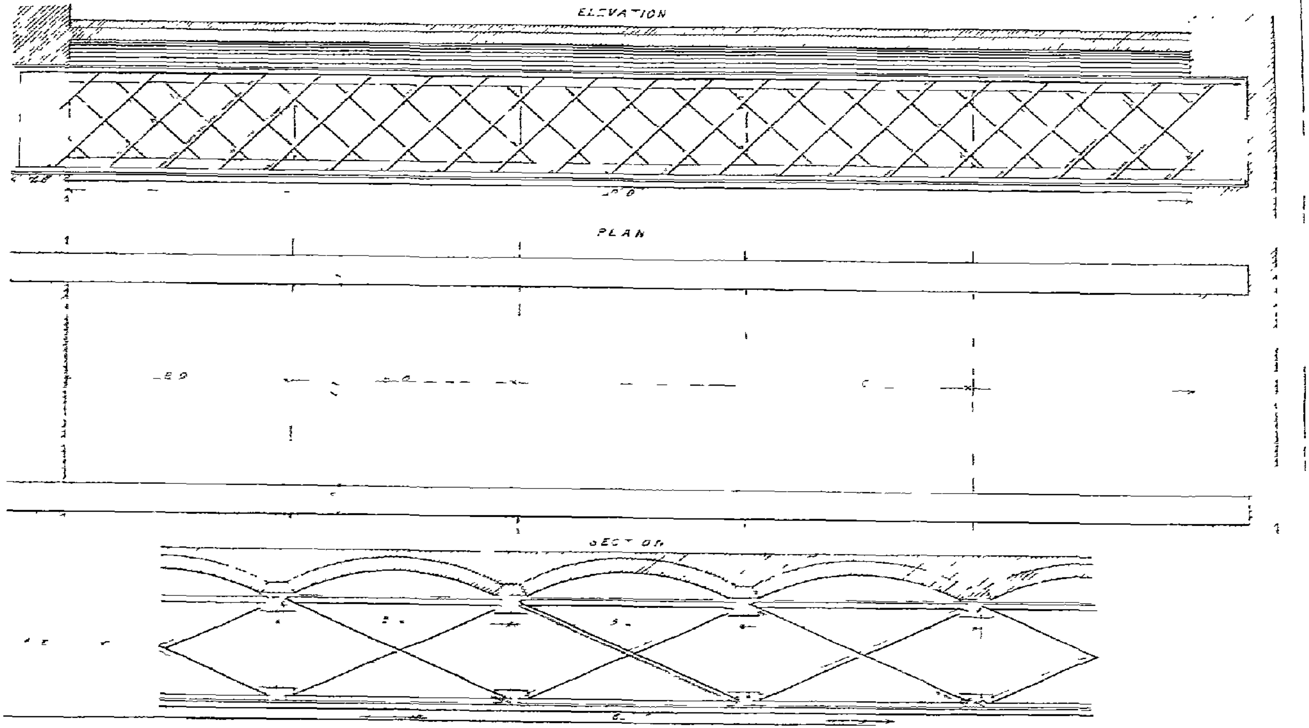

Girder for Rooms 20 feet wide
20 9"
of top flange 8 6 long
Tie rod for Rooms 20 wide
Section for AB
Girder for Rooms 10 feet wide
17 0"
Girder for Room 22 feet wide
Two angle irons
24 9"
Tie rod for girder

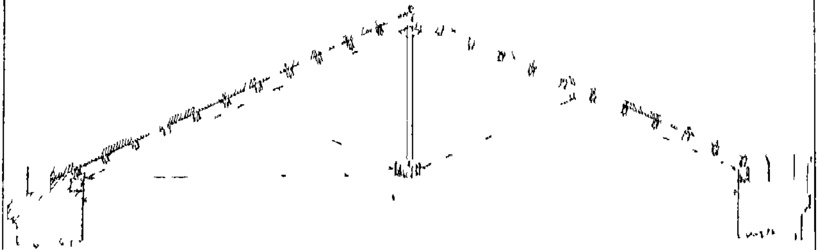
PLATE II

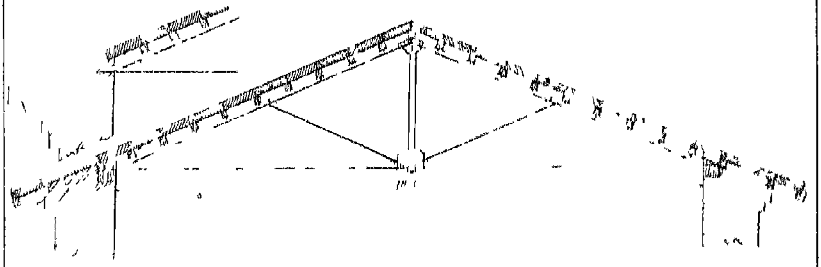
IRON ROOFING.

Girders for the Roof of the Deig Palace Bhurtpoor



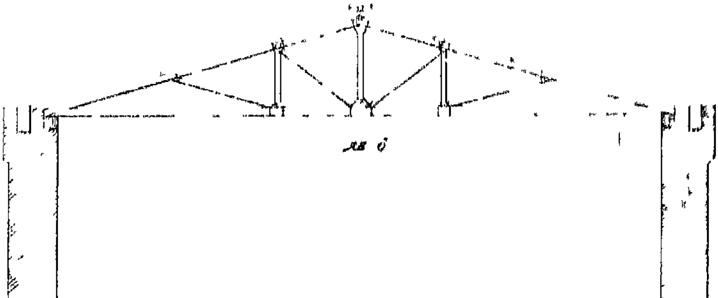
IRON ROOFING





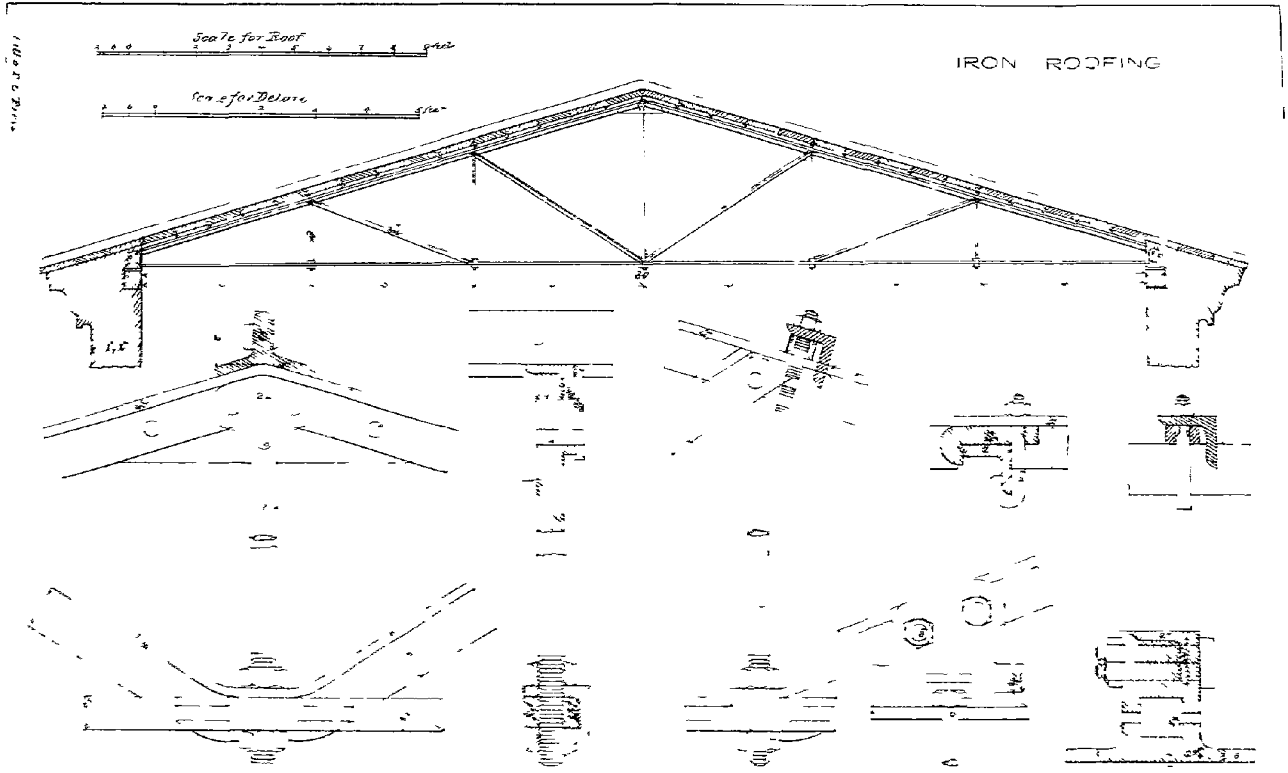
Scale [illegible] feet [illegible]

Iron Roof for the [illegible]



Scale of feet

PLATE VI



No. 5. Is a design that was got out for Canal chowkies; it was circulated amongst the Canal Officers, and resulted in orders being given for the iron work of two chowkies. For the roof of a room 20 feet square, three principals are required; which, at Rs 28 each, is Rs. 84, or 3 annas 4·3 pie per square foot.

No. 6. Was got out for the roof of the Scientific Hall, Allyghur. The price of each principal is Rs. 80, and the cost for a building 30 × 60 feet would be at the rate of 6 annas 4·8 pie per square foot; if the angle iron purlins are used, the cost of them and the principals would be at the rate of 14 annas 7 pie per square foot.

39. Annexed is a plan showing details of the roof of the new Custom-house at Rangoon: the calculations for strength and weight are given, as a useful example.

Columns for Upper Story to support Roof.

Weight of Roof.—Bearing beams $1 \times 11' \times \frac{15 \times 10}{144} \times 46{\cdot}61 = 531{\cdot}07$

Cross do., $2 \times 10' \times \frac{10 \times 6}{144} \times 46{\cdot}61 = 388{\cdot}41$

Joists, $18 \times 5\frac{1}{2} \times \frac{4 \times 4}{144} \times 46{\cdot}61 = \underline{512{\cdot}71}$ 1,435·19

Terracing and flat tiles $11 \times 10 \times 65 =$ 7,150·00

Total dead weight on each column, 8,585·19 lbs.

Let W = breaking weight for long columns by Hodgkinson's formula $= 44{\cdot}34 \frac{D^{3\cdot6} - d^{3\cdot6}}{L^{1\cdot7}}$, D being external diameter = 4 inches, d internal diameter = 3 inches, L the length = 15 feet. In this case $44{\cdot}34 \frac{4^{3\cdot6} - 3^{3\cdot6}}{15^{1\cdot7}} = 42{\cdot}11$; also c = crushing force of iron (44 tons) × sectional area of columns $= 0{\cdot}7854 \times (4^2 - 3^2) \times 44 = 241{\cdot}9$; then the actual breaking weight for short columns $= \frac{W\,c}{W + \frac{3}{4}c} = 45{\cdot}57$ tons, which taking the factor of safety as 4, gives the working load $= \frac{45{\cdot}57}{4} = 11{\cdot}34$ tons, or 25,401 lbs.; thus giving an excess of strength sufficient for all contingencies.

Columns for Lower Story, to support Flooring, with weight of Columns and Roof above.

Floor.—Bearing beam $11 \times \frac{17 \times 10}{144} \times 46{\cdot}61 = 605{\cdot}28$

Cross do., $2 \times 10 \times \frac{13 \times 9}{144} \times 46{\cdot}61 = 757{\cdot}41$

Joists, $18 \times 5\frac{1}{2} \times \frac{6 \times 4}{144} \times 46{\cdot}61 = \underline{769{\cdot}06}$ 2,131·75

Weight of tiles and mortar, - - - - -	7,150·00
„ of goods 11 × 10 × 400, - - - -	44,000·00
„ of columns of upper story, - - - -	600·00
„ of roof and each column, - - - -	8,585·19
Total dead weight on each column, -	62,466·94 lbs.

Let W = breaking weight of long columns $= 44{\cdot}34 \frac{D^{3\cdot6} - d^{3\cdot6}}{L^{1\cdot7}} = 284{\cdot}05$ tons, where D = external diameter = 7 inches, and d internal diameter of column $= 5\frac{1}{2}$

inches, L = length in feet = 15, also c = crushing force of iron × sectional area of column = $44 \times 0·7854 \times [7^2 - (5\frac{1}{2})^2] = 647·95$; then crushing weight for short column $= \dfrac{W c}{W + \frac{3}{4} c} = 239$ tons

Taking the factor of safety as 4, this will give a safe working load of $\dfrac{239}{4} = 59·75$ tons, or 133,840 lbs.; which will be sufficiently strong for all contingencies

Girders and Columns for Shed of Custom-House.—The columns are to be 15 feet long, placed at intervals of 20 feet apart, each supporting four trusses with roof covering and one girder of weight estimated below.—

WEIGHT OF GIRDERS.

	feet	lbs. per foot.	lbs.
Rafters,	40	8·25	330
Struts,	20	5·00	100
Purlins,	80	2·50	200
Tie-rod,	37	3·32	123
King-bolt,	6·5	2·00	13
Queen „	6·5	1·00	6·5
Ridge,	5	4·00	20
„ plate,	5	12·00	60
Tiles,	5 × 40	1·50	300
Gutter,	5	27·64	138·2

Total weight of truss and covering, = 1,290·7
Total weight on each girder 1,290·7 × 3 = 3,872·1

leaving the pressure of the wind out of consideration, as the roof is protected by the buildings.

Let W = breaking weight of girder
L = distance between points of support, - - - = 20 feet.
D = whole depth, - - - - - - - = 10 inches.
d = „ lower flange, - - - - - = 8 „
B = breadth of „ - - - - - = 8 „
b = thickness of web and rib, - - - - - = 1 „

$$\text{then } W = \frac{2}{3}\,\frac{BD^3-(B-b)d^3}{DL} = 14·72 \text{ tons.}$$

This gives a safe working load of $\dfrac{14·72}{4} = 3·68$ tons, or 8,243 lbs., to meet a dead weight of 3,872 lbs. equally distributed at three points, thus giving an excess of strength sufficient to meet any occasional pressure from wind, &c.

WEIGHT ON COLUMNS.

Each column supports four trusses with roof covering, and weight of girder.
Weight of 4 trusses = 4 × 1,290·7 - - - - - = 5,162·8
Weight of girder (estimated at), - - - - - - 1,768
6,930·8 lbs.

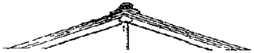
Columns are 15 feet long, 4 inches external and 3 inches internal diameter, which gives, by previous calculation, a safe working load of 11·34 *tons*, or 25,401 lbs.; this being sufficiently strong to meet any occasional strain from wind, &c.

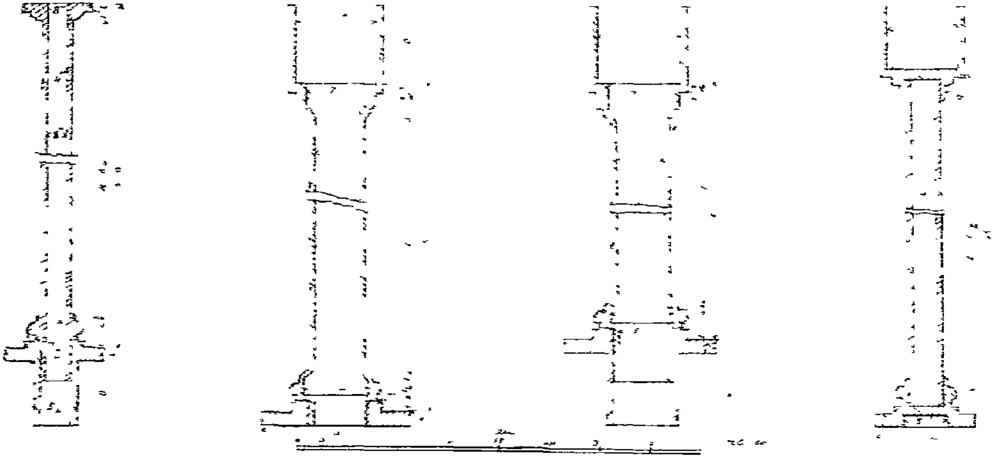
RANGOON CUSTOM HOUSE.

Detail of Iron Work

Span ....37 feet.
Rise in centre.............7 - 5"
Rise of Tie rod, ...—11⅛"
Dimension of Rafters, ..5' x ⅜ x 5½ x ½
Struts ....2½ x 5/16 x 23¼ x ⅝
Diameter of King Bolt. .. ⅞

Custom House Shed
Elevation of half Double Truss





Column for
Custom House Shed

Column for
[illegible] House

Column for Ground Floor
of Custom House

Column for Upper Floor
of Custom House

40. The walls of the building having been erected and roofed in, the interior plastered, and painted, colored or papered, and the flooring having been laid down, it only remains to describe the details of finishing it, so that it may be fit for residence.

Verandahs are generally considered indispensable in all Indian houses built in the plains; they protect much of the main walls from the direct rays of the sun, and shade the doors and windows from his glare, while giving a pleasant lounge in rainy weather. They may be from 6 to 12 feet wide, 8 to 12 feet high inside, and with a flat or sloping roof supported on arched openings or pillars and architraves. Their floors should be raised to the same level as that of the rooms, and steps provided outside. Much of the appearance of a house depends on the style of the verandah.

41. *Doors and Windows.*—Doors in Indian houses are generally made double, so as to occupy less space when open: they may be pannelled or glazed—or part pannelled and part glazed—they vary in size from 6 × 3 feet to 8 × 5 feet in the clear, and are hung on *choukuts* or door frames built into the masonry. When more light is wanted, rectangular or semicircular fan-lights may be fitted over them. For the external openings, Venetian doors may be added on the outside to keep off the glare and admit the breeze. Doors may be painted white, or stained and varnished Brass hinges and fastenings are a great improvement to their appearance, and the employment of colored glass has a good effect.

Windows are generally made like doors, the sash arrangement being seldom seen except in houses in the hill stations. Upper windows are usually provided for ventilation, moveable on a central pivot, so as to be opened by a cord from below; they should have sun-shades outside, of wood or iron.

42. The roof timbers of a flat roof are generally left exposed in case of attack by insects, and if stained and varnished, or painted, look well enough. The timbers of a pitched roof are generally covered by a *Ceiling cloth*, which should be carefully stretched on a frame, made in pieces, and securely nailed to the wall plates on the top of the cornice, and the bottom of the king-posts of the trusses.

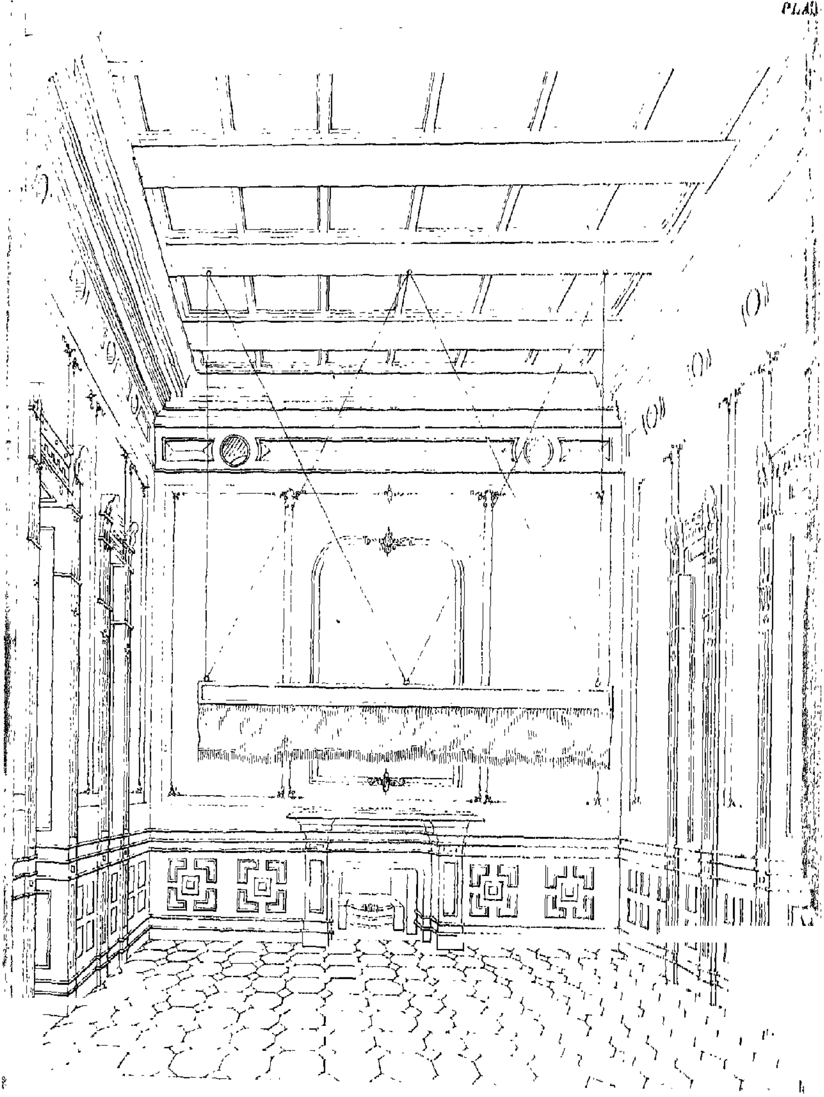
43. The construction of chimneys has been treated of above. As wood is used as fuel instead of coal in the *Fireplaces*, the iron grate may be dispensed with, and a small platform of masonry substituted, with a perforated iron plate to give a draught. The chimney-piece must be left to the taste and fancy of the architect, but the sides of the fireplace should be splayed out more than usual, in the colder provinces, to throw out the heat.

44. *Punkahs* may be hung from strong iron hooks screwed into one or more of the beams supporting a flat roof, or they may be suspended from the tie-beams in the case of a trussed roof; the framework should not be more than 18 inches wide, with a deep heavy fringe, and may be ornamented at pleasure. Sometimes a bar of carved heavy wood takes the place of the ordinary rectangular frame of wood and canvas. With brass rings and thin colored cord, with the framework tastefully painted, and the fringe prettily edged and of good material, punkahs may be made ornamental to a room, instead of being the unsightly excrescences they generally are.

A design for a drawing-room interior is given in the Plate.

DESIGN FOR DRAWING ROOM INTERIOR

PLA



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CHAPTER XXVII.

DESIGNING.

45. In designing a building, the first thing to be thought of, and one which should not be lost sight of throughout, is the object or objects it is to serve and all the requisites of strength, convenience, beauty and economy for the attainment thereof. By beauty is not to be understood the mere presence of ornament. A building utterly devoid of ornament may possess great beauty architecturally, from the perfection of its proportions generally, the variety of outline resulting from the projection of some of its parts and the difference of relief, *i. e.*, height, given to them, and its appearance of harmony with the use it is intended for; on the other hand, pretentious buildings, introducing columns, with elaborate entablatures and a multiplicity of mouldings, each good in and by itself, may be utterly devoid of all architectural beauty.

46. A very essential point to be attended to is *Ventilation;* the air entering by the doors should be able to escape by means of apertures in the roof, so that the whole of the air within the apartment may be frequently changed; and light should be admitted from above. It must be admitted however that the proper method of ventilating and cooling buildings in a tropical climate is not yet well understood. The ordinary rules for ventilation are often inapplicable in India owing to the extreme heat of the external atmosphere, which renders it necessary to exclude it entirely during the day, unless previously cooled by some artificial process. The ordinary method of doing this is by means of *tatties* or grass screens, placed in the doorways to windward and kept constantly wetted. This method is however evidently efficacious only when a strong breeze is blowing, and when the wind is dry and hot; when the air is moist and stagnant, the latter ceases to act, and it is necessary to create a current by artificial means, such as a *thermantidote*, or other species of blower; and in general the air inside the house is cooled temporarily by agitating it with *punkahs*, which however evidently serve no purpose of ventilation and do not even really lower the temperature. To secure a thorough draught through the rooms, numerous doors or windows are provided, and opposite to each other, and this answers well when a sea-breeze is blowing part of the day, or in ordinary cases when the external atmosphere is tolerably cool, at least at night. But more than this will be needed when the air is hot and stifling. The floor of the room should be raised and flues provided underneath through which cool air can be forced by machinery and admitted through minute perforations in the floor, and the foul air carried away through a perforated cornice above, or by ventilators in the roof.

47. Another point to be considered is the aspect of the building with reference to prevailing winds, use of tatties, topographical peculiarities of the neighbourhood, &c. In Upper India the long sides of barracks are generally made to face the west and east, so that one of these may be exposed to the westerly wind; as however a house whose long sides face the north and south is most sheltered from the sun, it is best so placed when westerly winds are not prevalent. This point determined, the out-offices must be distributed conveniently, yet so as not to interfere with the object sought in the first instance.

48. In dwelling houses, the habits and wants of the occupants must all be carefully considered; but these are so infinitely various that the young architect can be here only cautioned not to neglect them whenever called upon to prepare a design. Every kind of fitting, especially such as have reference to lighting, warming, ventilating or cooling the rooms, should be determined upon beforehand. The nature of the materials will next be considered as regulating the thickness of the walls; the relative position of the various rooms will, with reference to economy have to be regulated by the ease or otherwise with which they can be roofed, except in flat roofed buildings, wherein each room is roofed independently of the rest, and in such houses convenience can chiefly be studied, economy providing for as many *partition* walls as possible, which can be thinner than those supporting the beams of the roofs.

49. One of the first points to be determined in framing the design of a house, barrack, or other dwelling, will be whether the building is to consist of more than one storey or not. In Northern India, *Upper Storied Houses* are rare, chiefly because the ground is of little value and rooms arranged on one floor are more convenient, whilst the building itself is less expensive; but where ground is valuable, as in the Presidency towns, upper storied houses are common, and there is no doubt that rooms on an upper floor are far more healthy as dormitories. Indeed, in damp climates, such as Bengal or Burmah, they should be regarded as indispensable. The special points to be attended to in designing an upper storied building are—1st, That the foundations are strong enough to carry the weight of the building; 2nd, That the masonry of the walls is good and well bonded, and gradually diminished in thickness upwards, according to the number of the stories; 3rd, That due provision is made for the ventilation of the lower rooms; 4th, That convenient staircases are provided for ascent into the upper stories.

50. Every kind of building whether public or private will of course have to be designed according to the specific purpose for which it is intended; and so numerous are those purposes that it would be obviously impossible to enumerate or even classify them; a few hints may however be acceptable for the most common kind of buildings which the young Engineer in India may be called upon to design.

Private houses.—If on two stories, the sitting rooms should be arranged below, the bed rooms above; an entrance hall is a convenient arrangement in a large house, from which the principal staircase will ascend into the upper storey. The size of the rooms will be affected by various considerations, and their proportions also. For a drawing-room or library, if the length is half as much again as the breadth, and the height the same as the breadth, the effect will be harmonious; a dining room may be longer in proportion. Recesses may be provided in the walls of rooms for book-cases, for cupboards, or as niches for lamp or statuary, as the case may be; but sufficient wall space should be left for pictures.

Bow-rooms are generally admired and are often convenient, but all curved walls are more expensive than straight ones, as involving cutting and shaping of bricks. Bed-rooms should have dressing and bath-rooms conveniently provided, and the doors and windows carefully arranged as to position, so as to secure privacy.

Barracks.—Further on are given the latest approved designs for these buildings. Those hitherto constructed have generally consisted of a series of large wards, in which the cots are arranged against the walls on each side, with tables down the middle. Where double verandahs are provided, as in the Punjab Barracks, the inner ones are used as dining rooms. The new arrangement, however, by which the living rooms and bed rooms are separate, is in every way superior, though doubtless more expensive.

Churches.—Are usually built with a nave and aisles, and a chancel at the east end, when the ground plan would be a simple rectangular parallelogram; or the plan may be made cruciform by the addition of north and south transepts. The proportions and sizes of these will vary according to the number to be accomodated and the taste of the architect, and the additions of tower, porch, &c., must also be left to the architect and the sum he has at command. So many excellent specimens of Gothic churches, both large and small, have been erected in late years, that the young architect can have no excuse for designing the hideous abominations which used to be so common in this country. As a general rule, the Government in this country defrays the cost of the more building itself, all additions and ornamentations being paid for by subscription, and the architect should design his structure accordingly, so that gradually it may be made a structure worthy of a Christian congregation. Due attention must also be paid in his Gothic design for the requirements of the climate. Verandahs will generally be wanted to protect the walls from the direct rays of the sun, more openings for fresh air than are demanded in a cooler country, and apertures above for ventilation. The provision of all these in harmony with architectural requirements, will always prevent a more slavish copying of a European design.

51. As a commentary on the foregoing are appended a few fair examples of Indian buildings erected or designed, chiefly extracted from the *Professional Papers on Indian Engineering.*

Nowshera Barracks, Punjab—Each barrack accommodates one company, and consists of two wings connected by a passage 30 feet long.

In each wing there are four main rooms, 42 × 24 feet, with a reading-room or workshop, 26 × 16 feet, at one end; and four rooms 22 × 14 feet, for the accommodation of the Sergeants at the other end. The inner enclosed verandah is 12 feet wide with double doors. The outer verandah is open, 10 feet wide, the archways being 8 feet span.

The main walls are 22 feet in height from the level of the floor to the top of the stone templet, which receives the shoe of the iron trussed frames of the main roof. The roof is on a pitch of thirty degrees, and is formed of large Grecian tiles set in mortar, over 12 inch square bricks, 2 inches thick.

The walls of the inner verandah are 16 feet high from the level of the floor to

PLATE X.

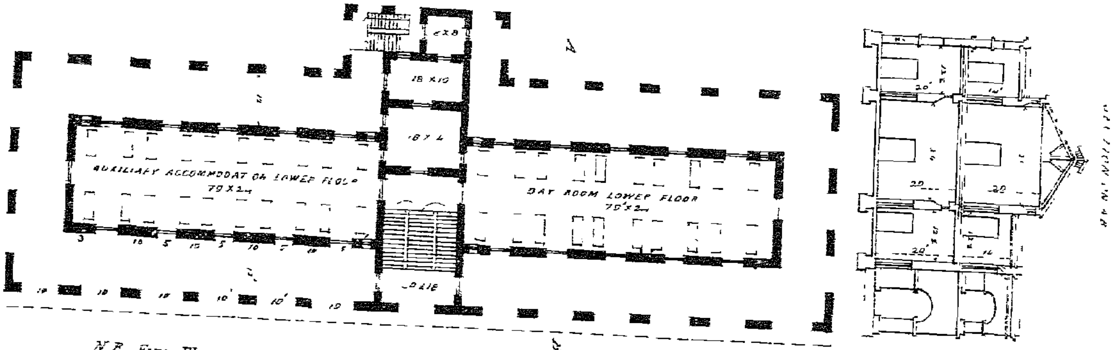
STANDARD PLANS OF INDIAN BARRACKS.

Nº 1

Plan of a double Storied Barrack suited for the unmarried men [illegible] whole -married men, the lower floor being set apart as day rooms and for auxiliary purposes –

Sup feet per man in dormitories 95 0"

Dº Dº Dº in day rooms 47 ½



N B Fire Places may be provided for the day rooms, but in the Lower floor only
The roof of the stair case and Serjeants Quarters should be flat and on a level with that of the verandah to admit of end ventilation of Wards by means of Clerestory windows

Scale 40 feet = 1 inch

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the bottom of the iron beams. The roof is flat, formed by arching from beam to beam, the underside being plastered, and the upper covered with one inch fine terrace, the spandrils being filled in level.

The walls of the outer verandah are 12 feet 9 inches high. The roof being flat pucka terrace, supported on deodar kurries, scantling 5 × 4 inches, placed 9 inches apart.

The masonry of the foundation and plinth is of slate stone and mortar, the latter having equal proportions (by measurement) of stone lime, soorkhee, and river sand.

The masonry of the superstructure is throughout of burnt brick and lime cement, in proportions as above.

The whole of the interior of the buildings is plastered with sand plaster, having washed sand and lime, in equal proportions (by measurement).

The exterior of the whole building is pointed, with exception of the cornices, which are plastered with a cement formed of lime and soorkhee, in equal proportions, well beaten and consolidated; 2 feet at the bottom of the outer walls and the outer face of the plinth are plastered similarly to the cornices.

The whole of the flooring is formed of slate slabs set in mortar, over two courses of bricks laid flat, earth being first filled in and rammed to obtain the necessary height.

The whole of the doors are pannelled, the frames being 2 inches thick, the windows, where practicable, are hung on the centre so as to open when required.

The punkahs are hung from iron rods at a height of 15 feet from the floor. For the purpose of ventilation the ridge of the main roof is perforated along its entire length, and in the inner verandah the iron tubular beams are left open at the extremities to admit a current of air through them into the building.

Estimated cost, exclusive of iron work, Rs. 72,447.

New Standard Barracks.—Plans are given of the standard barracks lately approved of by Government for European troops in this country, and the following are the decisions arrived at by the Government of India, on the most important points connected with their construction and arrangement.

The Government of India is of opinion that, if the general rules and principles to be observed in barrack construction be laid down, and if specimen plans suitable for different localities be provided, the preparation of designs for particular barracks may be properly left to the local officers.

For a Regiment of Infantry, half company barracks should be provided as the rule; but barracks for whole companies are admissible when convenience requires their adoption, as in a fort. Anything in excess of whole company barracks should only be resorted to when they are indispensable.

For a Regiment of Cavalry, barracks, each sufficiently large for a troop, should be adopted.

For a Light Field Battery of Artillery there should be three barracks, one for each division.

For a Garrison Battery of Artillery there may be one or two barracks as, from local circumstances, may be found most convenient.

By the above arrangements the numbers that will be collected under one roof will i.e., in the case of the Infantry and Artillery, about 44 men, and in the case of the Cavalry about 66 men.

As to the number of Rooms, four should be provided for a Company of Infantry and six rooms for a Battery of Light Field Artillery. Three rooms are sufficient for a Troop of Cavalry, three rooms should also suffice for a Garrison Company of Artillery, except where two barracks are provided, in which case there should be two rooms in each barrack, or in all four for the whole Company.

The precise proportion of single men per Company, Troop, or Battery, to be provided for has not yet been definitely decided; but the number of men to be placed in each room according to the above arrangement, will never be less than 16 or more than 24.

Double-storied barracks, in which the upper floors only are used as dormitories, and the lower ones as day-rooms and for auxiliary purposes, should be adopted, as a rule, in all parts of India.

In places where ground is restricted owing to any cause, three-storied buildings may be adopted, the two upper floors being used as dormitories.

In Forts or other places where the efficient ventilation of the lower floor is obstructed (by the immediate proximity of a rampart or a hill-side for instance), this floor should not be occupied by dwelling-rooms.

In Hill Stations it is not obligatory to provide upper-stories, but when circumstances render it convenient to adopt buildings of more than one story in height, there is no sanitary objection to the occupation of the lower, as well as of the upper floors as dormitories.

It has been decided in a general way, that one-half of the space shall be set apart for day-rooms for the men, one-fourth of the space as an open arcade, and one-fourth for auxiliary purposes, such as Store-room, Sergeants' Mess, Regimental Library, Recreation Room, &c., &c.

It should be understood that out-offices, such as privies, cook-rooms, &c., do not fall under the category of *auxiliary*, but under that of *subsidiary* accommodation.

The space in barrack dormitories should be as follows:—

In the Plains—

7½ running feet of wall space per man.
90 superficial feet per man.
Width of ward 24 feet.
Height of wards in both floors to wall plate, 20 feet.
This would give 1,800 cubic feet per man.

In Hill Stations—

7 running feet of wall space per man.
77 superficial feet per man.
Width of ward 22 feet.
Height of wards in both floors 16 to 18 feet, according to the altitude of the station.
This would give in the one case 1,232 and in the other 1,408 cubic feet per man.

The following rules should be strictly attended to in regard to the arrangement of beds in a ward, viz:—

That there shall be only two rows of beds in a ward; that no bed shall be placed so unsightly in Churches, will thus probably be obviated. The rain which beats through the outer arches only, will fall on the floor of the arcade, and be carried away through the down pipes. Small openings to act as ventilators have been placed in the passages of the ground floor, and light is also admitted through the deeply recessed windows at the east and west ends, and in the transepts.

Estimated cost, Rs. 1,51,131.

Attock Church, Punjab—The design is for a Church calculated to seat 250 persons.

Specification.—The building to consist of a Nave (16′ + 22′) with north Transept (21′ × 12′) and side Aisles, and a Chancel (61′ × 14′).

A Tower (10′ × 10′ internally), and rising to a total height of 71 feet, is placed on the east of the transept, at the angle formed by it with the nave, and this with a porch (11′ × 9′) opposite to it, completes the design.

The ground-floor of the tower is appropriated to the Vestry, and the first storey can serve, if required, as an Organ loft, since it opens into the nave, and can be approached by the steps and staircase on the north face of the tower, without going through the lower apartment.

The *masonry*, for the most part, to be of rough-dressed stone of the best description to be found in the neighbourhood, brick being used only in the columns of the Nave, the arch mouldings, and such other portions of the structure as may seem in process of contruction advisable. All external and exposed work to be carefully finished, and plaster to be given to the interior only.

The *flooring* to be of tiles (9 × 9 inches) red and gray laid diagonally over brick-on-edge, the upper floors of the Tower to be 1½-inch planking over joints 9 × 6 inches.

The *roof* of the Nave, Chancel, and Transept, to consist of tiles (or shingles) over planking, over rafters and purlins resting on substantial trusses, placed 11½ feet apart from centre to centre, corresponding to the pillars of the nave; one truss of the same pattern being given to the transept and chancel, respectively. The roof covering of the side Aisles to be similar to that of the nave, but with flying arches springing from the aisle walls in place of trusses. The pitch of the nave, transept, and chancel roof to be 51°, and of the side aisles 21°.

The Tower to be covered by a timber frame-work, sheeted with zinc, and terminating with an iron finial, with a standard at each angle; one being a lightning conductor, and having a greater elevation than the rest. The rod should pass to the ground in the angle formed by the two buttresses at the south-east corner of the tower.

The *doors* to be battened, with massive ornamental hinges, and *hung*; no chowkuts being used.

The *windows* to be glazed diagonally, and stained glass to be introduced if funds allow, giving the preference to the east and then to the west window.

Sittings (of stained deodar) to be provided for 250 persons, the benches being so arranged as to occupy the whole of the nave, the north and south aisles forming the means of ingress and exit. The remainder of the *fittings*, comprising pulpit, reading desk, and chancel rail, to be of sissoo or walnut wood.

The *punkahs* to consist of deep and full fringes, weighted with lead, and attached to ornamental bars of sissoo, suspended from the iron ties of the roof-trusses.

The *font* to be of stone, carved at Delhi.

Third Class Railway Station, E. I. R.—Of brick throughout, pointed externally, and plastered inside. The roofs of tiling or pucka terrace, on strong trusses, or of brick arches with iron tie-rods.

European Hospital, Bombay.—The premiated design here given is a good example of the superior Architecture now coming into vogue wherever the money can be afforded for a higher style of building.

The Hospital is designed in the Gothic style of Architecture, which the author believes to be the style of all others best suited to the requirements of a tropical country. In the present design, that type of Gothic worked out in the South of Europe in the middle ages has been preferred to the more Northern type, the architectural requirements of India being more nearly allied to those of Italy than of England; various modifications of this style now universally adopted to meet modern necessities have been made.

The Hospital is 480 feet in extreme length, and 145½ feet breadth at the centre, the projecting end terminations are 68¼ feet in breadth, the ordinary breadth of the building being 58¼ feet. The building is entered at the centre on both East and West facades through covered carriage Porches, that on the West carrying above a small Chapel. An open Arcade leads from the portico steps into a large Octagon Hall, in which are placed two flights of stairs conveniently situated for those entering the building from opposite sides. The two flights are carried up to the upper floor of the building and they are lighted from above by four rose Windows. To increase this moderate light to a strong one and to add to the vertical ventilation of the building, as well as to produce a feature giving by its external appearance a unity of effect to the whole, which otherwise from its enormous size would be wanting in that unity, a lofty octagonal Lantern has been designed as the crowning member of the composition.

The urinaries, though included in the main building are completely cut off from the wards. Lofty openings slightly screened by shafts and simple tracery admit of a very thorough ventilation.

The building was intended to be constructed of Coorla rubble, a reddish trap, the arch rings being formed of alternate stones of Porebunder (whitish lime-stone) and blue basalt. The roof to be of iron, well ventilated, with numerous Domer windows above the ceilings fitted with louvers.

Estimated cost, Rs. 3,79,995.

E. I. RAILWAY, N. W. P.

Third class Passenger Station

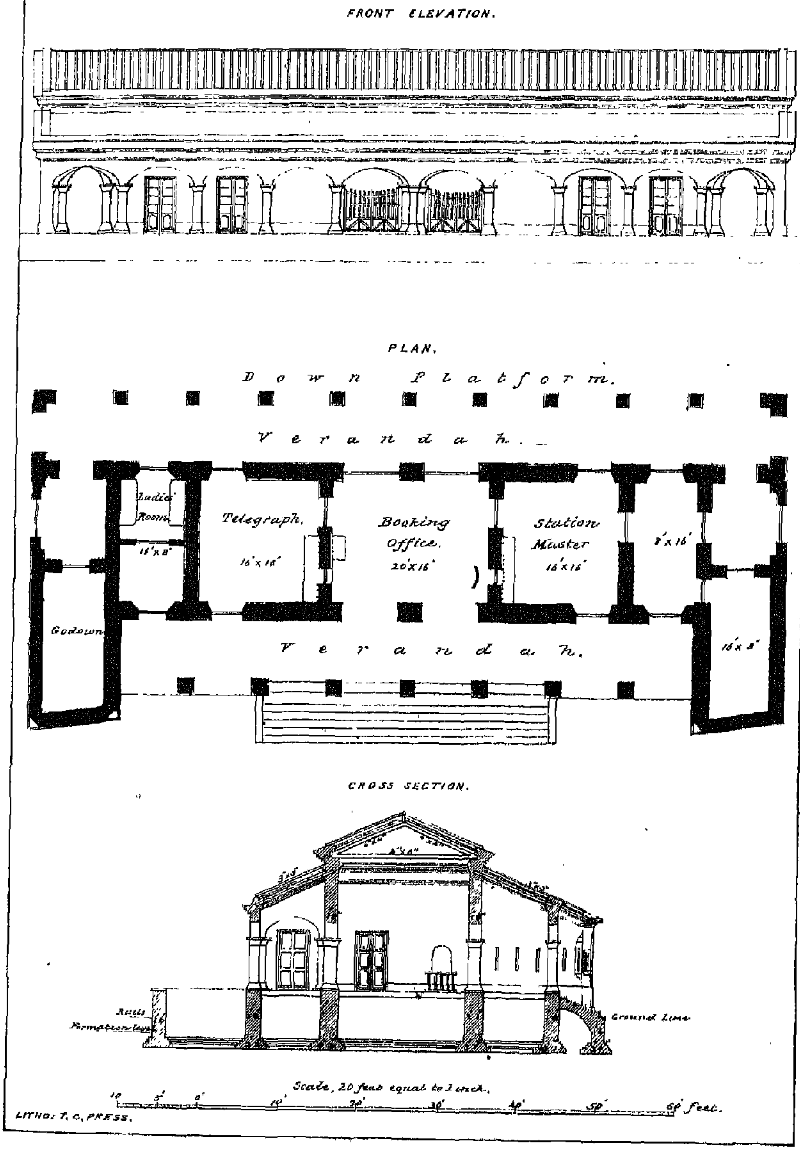

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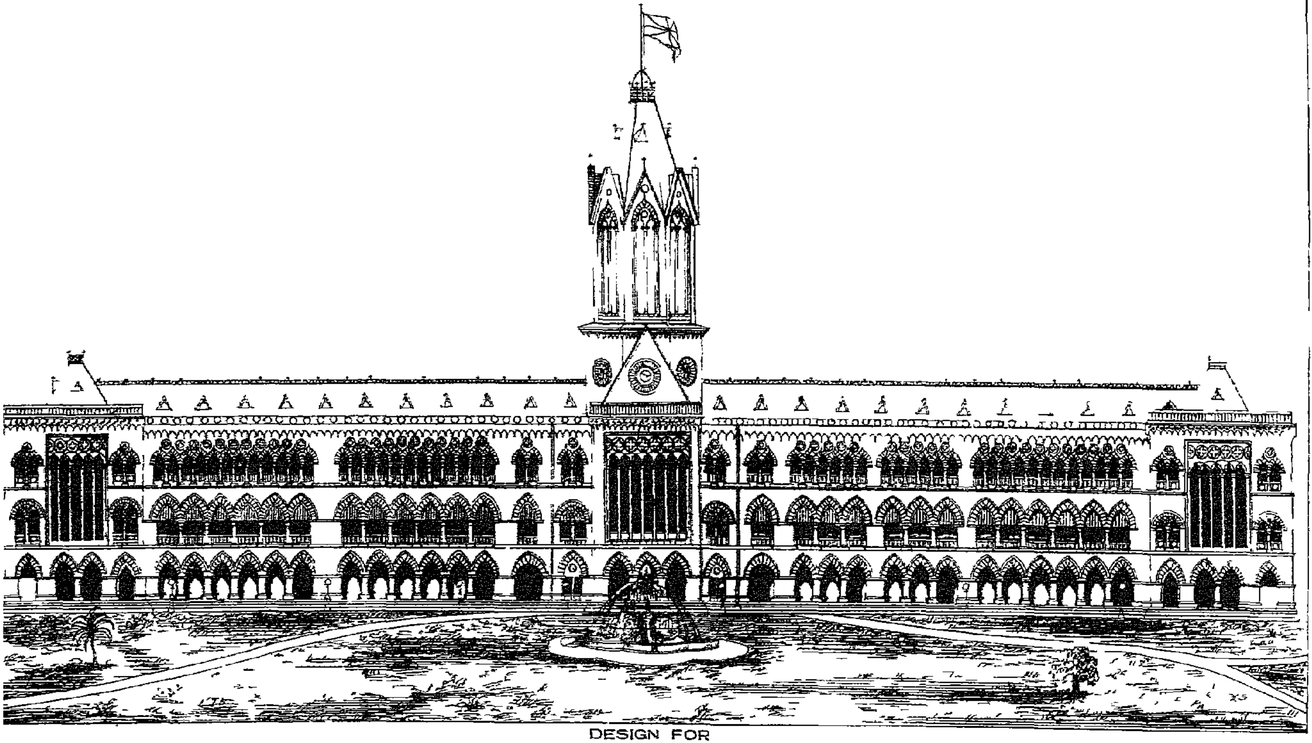
PLATE XVI.



DESIGN FOR

EUROPEAN GENERAL HOSPITAL—BOMBAY

CHAPTER XXVIII.

SPECIFICATION AND ESTIMATE.

52. The design being determined upon, the next step is to draw a ground plan at the floor level, with vertical sections, showing every dimension requisite for the calculation in full, of the cubic, superficial, and lineal measurement, of every part of the building. Besides these, working plans on a larger scale must be given showing the roof trusses, mouldings of cornices, framing of doors and every detail, especially those which cannot be accurately described by words in the specification, which is now to be made out.

53. The *Specification* is a description of the work to be erected, which, with the assistance of the plans, shall be sufficient to determine precisely beforehand everything to the minutest particular to be done by the builder, and this more especially if the builder is a contractor also, as otherwise no honest contractor is likely to undertake it; if the specification is not precise, more may be expected from him than he is able to perform for the sum at which he offers to do it; or he may take advantage of this want of precision, to give inferior work within the letter of his bond.

The more minute a specification, the more fit it is to be the subject of a contract, and the better guide it is to a builder whose *bonâ fide* expenditure is guaranteed to him with either a percentage on outlay, a salary whilst employed, or a fixed sum for superintendence of the work on its completion.

A specification should state the nature of the materials to be used in every part of the building; for instance, the kind of brick or stone to be used in the foundation, the particular kind and the proportions of lime and sand or soorkhee in the mortar; the same of the plinth and superstructure; the nature of the plaster, varying perhaps in different parts of the building; of the floors in each room, the ceiling, roof, doors, in short every item of work must be accurately described as to its quality and situation; the quantities have next to be ascertained, and this is what is commonly called Estimating.

54. *Estimating*, consists in measuring correctly the whole of the work to be done in a building, keeping every kind of work separate, and then calculating from these measurements, the quantities in cubic, superficial or lineal feet of each, according to its nature. Then, having ascertained, either by experiments carefully conducted, or from previous experience carefully recorded in a tabular form, the quantities of every kind of material used and expended in some fixed quantity, generally 100 feet of each kind of work, the quantities required for the whole building are then calculated, and the price of each being ascertained, the probable cost of the building, barring accident and changes in the price of materials and labor, becomes known.

In taking out quantities for an estimate, it is convenient to follow some fixed rules in order to prevent omission; for instance to begin with the walls of the foundations, then the plinth, then of each story separately.

In buildings which are uniform in plan, the different parts can be sufficiently described in words, as, outer long walls, main long walls, partition walls in verandahs, &c.; in buildings whose plan is intricate this would not be sufficient, and a horizontal section of each story must be given, and each wall marked with distinguishing letters—thus, walls, *a*, *b*, *c*, *x*, *y*, &c.

Walls having the same thickness and height should be set down in sequence, so that their lengths being added together, their sum multiplied by their common thickness and height, gives the cubic measure of the whole.

To prevent the calculation being too laborious, it is not usual to measure Masonry more minutely than to the nearest quarter of a foot, and splayed jambs, &c., are calculated as square, the largest dimension being taken, to compensate for the extra labor of cutting the bricks to gauge; and other such like arbitrary rules are followed, which can only in the first instance be left to the judgment of the estimator, and afterwards to the practice of the Department, on which the revision of the estimate devolves.

The value of Wood-work in India will generally be in direct proportion to the scantling; the extra labor in sawing up small scantlings being made up for, by the fact, that timber of the larger scantlings costs more in handling and putting up, and is more difficult to get without flaw. Very small scantlings which can be cut out of side slabs, sawn off from round timber to reduce it to a rectangular form, are generally cheap.

In Roofs, the timber should always be calculated separately in cubic feet from the superficial covering—bolts and straps in trusses should be enumerated and their weight ascertained. In heavy trusses allowance must be made for the cost of setting them up, as they cost a good deal more in moving and handling than untrussed and lighter timber.

55. The first object of an estimate is that the person directing the construction of a building, should know beforehand what it will cost; and if the estimate is greater than the sum available for its construction, in what particulars its cost may be reduced, either by retrenching its extent or changing the nature of the materials to be used in its construction.

After the estimate for a work has been sanctioned, the person on whom devolves the duty of constructing it, should know the quantity of materials required, and average number of workpeople of each sort that will have to be employed; knowing this, it will be his duty to take care that the workpeople are properly apportioned to each kind of work, that an average quantity of work shall under ordinary circumstances be exacted from them, and that they are never delayed by materials not being always on the work and at hand.

A daily record of expenditure being subsequently kept under headings copied from the details which appear in the estimate, the differences which may occur between the estimate and real cost can be assigned to their right places, and their true causes traced for future guidance, and thus the estimates and accounts become a check on each other. In order to their being so, it is evident that every heading in the estimate must correspond with a similar heading in the accounts.

By frequent measurement of the work and comparison with the quantities of each kind, which ought to be performed by the men employed, the overseer will be able to check idleness; if practicable, the workpeople should be paid at fixed intervals, and their work measured before each payment.

The estimate will likewise enable the Engineer to calculate how long his work is likely to take according to the number of workpeople employed, which is regulated, either by the number procurable, by the extent of the work which allows only a certain number to be spread over it without interference with each other, or by the means of making arrangements for their being provided with materials; he will also be able to apportion the right number of workpeople of each kind, taking care to watch this apportionment, to judge whether peculiar circumstances may not render it inappropriate, and whether some better proportion many not be devised.

Forethought will especially be requisite as regards woodwork and fittings, that they shall be ready beforehand so as not to delay the bricklayers; also that scaffolding is prepared in advance, that laborers bringing materials shall carry them with the least expenditure of labor, and that therefore the approaches are made easy for them so as to occasion no waste of their time or strength.

56. The following is abridged from the P. W. Code:—

The papers to be submitted with any project will consist of a Report, Specification, and a detailed Calculation of measurements and quantities, with an Abstract showing the total estimated cost of each description of work. These documents together form what is commonly called "the Estimate," though the term more properly denotes the two latter only.

The heading of every Estimate shall specify clearly, but in general terms, the nature of the work to be done, and the locality. When not at one of the principal stations, the pergunnah and zillah, as well as the town or village, must be mentioned.

The heading will be followed by a list of references, embracing the authority on which the Estimate is framed and all the correspondence on the subject.

After the list of references will be inserted the Report, stating in brief terms the object to be gained by the execution of the work estimated for; discussing the reasons for the adoption of the estimated project or design in preference to others; and explaining any peculiarities which require elucidation. The time within which the work may be expected to be completed must also be mentioned.

After this will follow the Specification, which must show fully and clearly, but as briefly as possible, the details of the work, how each portion is to done, and what materials are to be used (see above).

57. A Specification should commence with a general description of the locality or proposed site of the work, unless a more detailed report is called for. For works such as bridges, docks, roads, canals, &c., minute detail of localities and their adjuncts are necessary; and in general a block plan should be given for reference, on which will be shown the drains, sewers, &c. The specification should next proceed to an account of the work itself; that is, its intent and purpose, character, arrangement, and style.

The specification should then give a complete detail of construction and materials, and should be divided (supposing a building with a roof) into the different parts as they generally occur in construction, viz.:—

1stly. The preparation for the Foundation either on the natural soil after excavation, or by artificial means such as piling, concrete, framing, curbs, &c.; and in connection with this subject should be detailed, the mode of drainage, the disposition of open or covered drains, sewers, &c.

2ndly. The Brick-work of foundation, plinth and superstructure, detailing the kind of plastering, and whether on one or two sides, white-washing, coloring or painting, with the nature of the materials to be used.

3rdly. Stone-work, the kind of stone, and how connected, whether by cement or iron cramps.

4thly. The Roof, whether timber or iron; its nature, construction, detail of component parts; its covering, whether tiles, bricks, planks, thatch, &c.; means to be adopted (if any) for seasoning the timber, or preventing its destruction by moisture, or white ants, and brief calculation of the proof that it is capable of sustaining, the weight to be assigned to it.

5thly. The Flooring, its nature, mode of raising, whether solid or by flues; means (if any) for prevention of damp.

6thly. The Doors and Windows, the material of which composed, construction, mode of hanging and fastening.

7thly. All Iron-work unconnected with the foregoing items; such as railing, gratings, wall-ties, &c.

8thly. The Painting of all kinds and colors, Varnishing, &c.; and lastly, the Fittings and fixtures, such as staircases if of wood (if of masonry they will come under that head); sunshades, ceilings, partitions, fire-grates punkahs, mats, water-closets, pumps, cisterns, &c.

The conclusion should show the means of clearing away all rubbish and spare materials, formation of roads or walks, trimming, clearing the ground, and placing it with out-offices, walls of enclosure, &c. (specified for as above), in a proper state to be finally surveyed or made over to the authority for whom it is destined.

FORM OF SPECIFICATION.

58. *Foundation*.—All rock, soil, or rubbish necessary to leave the site of intended building clear and unencumbered, foundations for footings of all drains, cess-pools, vaults, &c., to be properly excavated, refilled, rammed, and levelled, draining off all water and soil which may affect the excavations from springs, currents or drains. The excavations or beds of all footings to be made level and perfectly consolidated, the depths and widths as shown in drawing No. *Fig.*

N.B.—Nature of soil upon which the foundations are to be placed to be ascertained previous to framing estimate, by boring, and all previous information collected to avoid as much as possible future deviations from plans.

An artificial Foundation to be made for (certain parts of, or) the entire building (for reasons given) feet in width and feet deep, the same to be composed of one part of fresh quick lime, three of coarse sharp sand, and six of broken stone or vitrified brick; or two parts of stone (or *kunk*) and one of sand with as much lime as will make good concreted mortar with the latter; to be mixed in small quantities, the lime being moderately slaked at the time of admixture, and the whole thrown from a height of not less than 10 feet into the trenches; the foundations being formed in successive layers of 6 inches thick, till the required depth is obtained.

An artificial Foundation to be made for (certain parts of, or) the footings of the entire buildings with sound piles feet long inches diameter pointed with iron and iron-hooped, to be driven by proper apparatus, the situation and relative distance to be as as shown by sketch, *Fig.* ( ) sleepers ″ × ″ over each row of piles and ″ planks of wood properly spiked over them.

59. *Brick-work*.—The Brick-work to be English bond, constructed with hard burnt, sound bricks ″ × ″ × ″ laid in mortar composed of part lime and parts clean sharp sand, or the best well-burnt and sifted soorkhee, the footings and walls to be of the varying heights and thicknesses figured in the drawings.

Flat and counter or relieving arches to be turned through the entire thickness of walls of (1 or 1½) bricks deep over all lintels and bressummers.

Inverted arches under external or other openings from pier to pier, as shown in *Fig.* ( ).

Basement walls to level of lower floor to be plastered externally, and remainder on both sides with $\left\{\begin{array}{c}\text{sand}\\ \text{soorkhee}\end{array}\right\}$ plaster, and interior of rooms to be finished off with the best lime plaster and white-washed, three coats. A cornice of brick-work, as per annexed sketch, to be constructed along walls projecting inches, with proper moulding well plastered.

Balustrades, as per sketch (to be given in the margin) to be continued along walls, composed of plinth, pedestals, and coping, cemented together and plastered.

The angles of walls to be finished with (*roughly wrought*) or (fair wrought) chamfer channelled quoins as per form in *Fig.* ( ).

60. *Stone work*.—Staircase, or steps at to be of stone 1 inch thick, tread to be 15 inches wide, and risers 6 inches, nosings moulded, with hand rail of cast-iron or wood. rooms or courts to be paved with stone inches thick, bedded on solid bottom of beaten rubbish and jointed in mortar.

If Gothic design, the buttresses, gable caps, or pinnacles, to be alluded to with details and marginal sketches

Plinth under columns to be formed of top and side casing of stone properly bedded on the brick-work, of section and form as per sketch *Fig.* ( ) cemented with best mortar and iron cramped, columns or piers to be of stone, with moulded capitals and bases, plain (or fluted) shafts.

Arches whether with archivolts or radiating stones, plain or otherwise; piers, keystones and springing stones. Wall of to be stone capped of sectional form as shown in *Fig.* ( ) or marginal sketch.

Marble.— Rooms to be paved with marble executed with finest possible joint, levelled and uniformly and thoroughly polished; paving to be not less than inches thick on a course of brick flat firmly bedded in well rammed brick rubbish.

61. *Roof.*—The roof over to be flat. The beams of wood, scantling $'' \times ''$ well seasoned, placed 3 feet apart from centre to centre and having 18 inches rest on the walls, on wall plates of (continuous or otherwise) openings $'' \times ''$ to be left round the beams for ventilation. Burgahs of wood $'' \times ''$ placed 1 foot between centres. The whole of the wood-work to be submitted to a process of saturation in chloride of zinc; or coated, at the wall rests, with coal tar laid on hot, or yellow orpiment. The covering to be of tiles inches thick, each closely jointed together with mortar, the upper layer well cemented, proper arrangements in the level being made for the perfect drainage, and by scupper holes with gratings at the mouths leading to vertical (earthen or iron) pipes inserted in the wall, or to earthen well baked spouts (with or without horizontal gutter).

Or, Covering to be of two well-burnt tiles jointed with mortar and 6 inches thickness of terrace, formed of six parts large and small semi-vitrified koah with as much lime as will cement the whole; the mass to be laid on in two layers, well beaten down to 4 inches, and finished with well beaten soorkhee terrace and lime coating.

Or, Roof to be timber trussed as per detail in *Fig.* ( ) trusses to be not more than feet apart, scantling as below, viz.:—

Rafters	″ × ″
Tie-beam	″ × ″
Struts	″ × ″
Purlins	″ × ″
King-post	″ × ″

&c., &c.

Or, Rafters framed on to tie-beams and iron strapped, tie-beam to have a rest of 18 inches on wall, king-post to be united to tie-beam with iron strap and bolts, struts dove-tailed into shoulders of king-post, and ridge pole notched on to head of the same. The whole of timber well seasoned, and submitted to saturation in chloride of zinc or coal tarred; battens or purlins ″ × ″ apart, to receive pantiles, or two flat tiles, or terrace (as above), or one flat tile jointed in mortar, and over that Grecian tiles laid as per *Fig.* ( ) Eaves of roof finished with boards ″ × ″ and rain water gutters (or without) of zinc, sheet-iron, or semi-cylindrical earthen drain tiles.

Or, Roof of cast-iron beams as per section, *Fig.* ( ) placed 6 feet apart, from the flanks of which to spring single brick arches in cement rising 9 inches. The whole to be terraced over with a thickness of 3 inches well beaten koah, between which and the arch, may be inserted a thin layer ⅜-inch of asphalte or coal tar and forge ashes.

(*N.B.*—The above construction answers very well for godowns of either one or two stories, jails, arsenals, barracks, &c.)

Or, Roof of wrought-iron trusses placed 6 feet apart as per *Fig.* ( ); principals to of **T** or flat bar iron ″ × ″; tie-rods and tension rods of section, respectively, as marked on the detailed sketches; rafters abutting in a king-head of cast-iron, which also receives the upper ends of tension rods. The feet of rafters let into cast-iron shoes resting on the walls, and to which are bolted the ends of the tie-rods. The struts of cast-iron, lower ends formed as a jaw to receive the tension rod, and the rafters bolted through the upper ends with ⅝-inch bolts.

Battens of ∠ (or square or flat bar iron) ″ × ″ rivetted to rafters inches apart or battens of (teak or saul) ″ × ″ ridge pieces of cast-iron with caps overlapping the upper layer of tiles.

The covering of either of the kinds mentioned above.

62. *Flooring.*—The floors of room to be flued as per *Fig.* ( ) showing plan and section, piers and openings, the arches to be single brick well jointed, spandrells roughly filled in, and the whole finished off with a terrace 4 inches thick, of well-beaten koah and lime coated, (or left rough to receive ½-inch layer of asphalte).

Or, Floor to be filled in with earth and well-rammed rubbish, over which to be a course of brick flat in mortar and terrace as above, or square tiles in cement close jointed, or, brick-on-edge with best burnt square bricks, set with close joints, over a brick flat in mortar.

Or, teak boarded, planks well seasoned and inches thick, screwed down to sleepers, saturated in chloride of zinc, or coal tarred; scantling ″ × ″ resting on blocks of good masonry ″ × ″

63. *Doors.*—Doors of to be of wood (double or single) planks with bedded joints, nailed to three back braces, and hung with hinges to a wood frame ″ × ″ (lock or latch).

The to have doors of 2 inches thick framing, filled in with inch battens of wood properly seasoned, and backed with diagonal braces hung with wrought-iron **H** or **|-L** hinges to frame ″ × ″ of wood (lock or latch).

(*N.B.*—Such are proper for godowns, coach-houses, barrack out-offices, &c., and may be made either with or without swing bar, and strong iron rolls.)

The to have 1 or 1½ inch wood panel doors hung with (brass or iron) butt hinges to frame ″ × ″ lock of (brass or iron) and inch slide (thumb or knobbed) bolts.

The to have (entire, half or two-thirds) glazed doors (or windows) frame 2 inches thick wood, with $\frac{3}{4}$-inch thick beddings to receive glass ″ × ″ panels of 1 or $1\frac{1}{2}$ inch wood, with edge mouldings, and hung to (single or double) rebated frame ″ × ″ by (iron or brass) butt hinges, and furnished with inch sliding bolts and lock.

The to be fitted with (entire or) two-third venetian valved doors (or windows) frames 2 inches thick of wood, well seasoned valves $\frac{1}{2}$ or $\frac{3}{4}$-inch thick, close fitting and weather tight, hung with **H** or **I-L** hinges to frame ″ × ″ (double or single) rebated (in connexion with, or) independent of the glazed doors or windows as above to be fitted with sliding (thumb or knobbed) bolts inches long.

(*N.B.*—Italian windows, fan-lights, and other varieties will of course be mentioned, as also whether the above are "single flapped" or double folding doors.)

64. *Iron-work.*—The posts as per *Fig.* ( ) or marginal sketch, to be of wood ″ × ″ with cast-iron boxed and tenoned caps and bases. Cast-iron columns to support to be cast hollow, outer diameter inches, and metal one-fifth of that diameter in thickness, cast-iron plates as per *Fig.* ( ), bases let into stone blocks ″ × ″ and run with lead. Cast or wrought-iron grating to be fitted to air holes in the basement ″ × ″ also to gutter drains of

Iron railing (cast or wrought) where shown in drawing to be fixed (if to wood, with screw bolts; if to stone, to be run with lead) also the rails or balusters to landing steps, balconies or verandahs feet high with (iron or wood) handrail.

Iron barred frames to be fixed to the windows of inch square bars let into horizontal flat iron 3″ × $\frac{3}{4}$″ screwed to the soffit and sill of wooden frame ″ × ″

65. *Painting.*—Wood-work of roof to be painted with color in oil (3 or 4) coats doors (glazed, panel, or venetians) of to be painted in oil color, three coats, the paint to have the proper mixture of best turpentine and linseed oil (Europe) to ensure quick drying.

Other wood work, if any, to be mentioned, and also any partitions, doors, hand-rails, &c., requiring varnishing merely (two coats).

66. *Fittings.*—Staircase at of wood framed into skirting, with 15″ treads and 6″ risers, moulded nosings, hand-rail, with cap, &c.,

supported at angles with wrought-iron column inches diameter

Punkahs ′ × ′ of 4-inch wide framing of wood, covered with cloth, painted color and hung to iron or brass hooks in the beams, with cords, brass pullies and pulling ropes to be provided, and fringe inches deep.

Here also mention any other fittings necessary or where emergently applied for and applicable to the building.

67. *Estimate.*—Every Estimate, not being for ordinary repairs, must be accompanied by drawings of the work to be done, showing the dimensions of each part.

Every Estimate shall contain, distinct from the specification, a statement of the detailed measurements of the works agreeably to the drawings, with calculations of the entire quantity of each kind of work to be done, in cubic, superficial, or running feet, or otherwise, according to the nature of the work.

Estimates shall be made out agreeably to the following form:—

DETAIL OF WORK.	No.	MEASUREMENTS.			QUANTITIES.		
		L.	B.	H.			

All Estimates must have Abstracts, showing the cost in Rupees of each kind of work, at so much per foot, or per hundred cubic, superficial, or running foot; which Abstracts must be so drawn out as to show distinctly the cost of each building or work included in the Estimates, as well as the total quantity, rate and cost of each kind of work to be done.

A charge of 5 per cent. for unforeseen contingencies must be added to the Abstract of every Estimate.

Every Estimate must be in all respects complete and intelligible without reference to any document but the drawings.

The rates of Estimates must be calculated to cover the expense of the Work Establishment, as well as the cost of sheds for materials and workmen. Extra Establishments must be applied for separately.

68. In framing Estimates the following points must be attended to:—

I. Every kind of work must be estimated by the cubic, superficial, or running foot, or 100 cubic, superficial or running feet, or by the maund, except in the case of miscellaneous petty works, which should be entered as petty works in Carpenters', Blacksmiths', or Masons' (or other Artificers') work, as per list, and each kept separate as far as practicable.

II. In estimating the brick-work for buildings the cost of excavation for foundations will fall upon the rate of brickwork, which will be all included in one item, embracing foundation, plinth and superstructure. Two-thirds of the contents of openings must be deducted in calculating the quantity of brick-work in the walls, in all cases where the opening is to be covered by a single flat arch; but when a second or discharging arch is to be turned, one-third only of the openings will be deducted; if the opening be covered by an elliptic or circular arch only, the opening will be deducted to the springing, leaving the contents of the head to cover the expense of arching. All splays will be calculated square.

III. Plastering, painting, and white or color-washing must never be mixed up with masonry, but will be separate items. Inside and outside work of these descriptions may be included in one item at an average rate.

IV. Timber-framing is to be estimated by the cubic foot, and the calculation must be shown in the detail of measurements in the same way as the calculation of brick-work. This mode is applicable to all wood-work, such as beams, burgahs, trusses, rafters, and other parts of roofs, wall-plates, architraves, door-frames, &c., &c., &c., and the rate will include the cost of raising and fixing, but not painting.

V. The scantling and distance apart of the timbers and the thickness of the covering of roofs must be stated, and the authority or calculation on which the scantling of the timber has been fixed.

VI. Covering-in roofs must never be included in the same item with the timbering; each separate kind of covering will form a distinct item.

VII. Doors, windows, weather-boarding and planking, and gratings of all kinds, will be estimated by the superficial foot. Glazed, panel, and venetian doors and windows, may be all placed in one item at an average rate, and batten-doors and other kinds of planking will be placed in one or more other items, as may be convenient.

VIII. Painting will always be a separate item from wood-work. Each kind of painting will be a distinct item. Painting venetians may be estimated by calculating the superficial area at 50 per cent. in excess of a plain surface of the same size; and the glazed part of windows and doors may be allowed for, by deducting one-third of the gross area calculated as a plain surface.

IX. Cornices and mouldings must in ordinary cases be estimated by the superficial area; the calculation to be made by adding the projection to the depth, multiplying the sum by the length, and doubling the product to cover the extra expense of moulding. The projections made in the brick-work should be taken as rectangular, calculated in cubic feet and included in the brick-work.

X. For iron-work, the weight must be calculated from the dimensions in the "detail of measurements," and the cost estimated by the maund; coarse, and fine wrought-iron may be separate items; as also cast-iron. A cubic inch of wrought-iron weighs about 0·136 of a seer, or 0·0034 of a maund. A cubic inch of cast-iron weighs about 0·128 of a seer or 0·0032 of a maund.

XI. When any work is to be done which is not specified above, the Executive Engineer should endeavour to divide the charge into items, according to the order in which the work is done; so that the Daily Abstracts may be furnished separately for each separate item, and thus the rates of work will be readily compared with the rates of the Estimate.

XII. No fractions of the cubic, superficial, or running foot are allowed in the calculated quantities where the work is estimated by the 100 feet, and only fractions to the extent of two places of decimals where the work is estimated by the foot.

XIII. No fractions of a rupee (*i. e.*, no annas or pies) are to be allowed in any Estimate, except when necessary to accuracy in the rates, and then the fraction must be as simple as possible; decimals of the rupee may be used in rates.

XIV. When any fraction of a rupee or of a foot occurs in calculation and is omitted, the sum will be increased by a unit, if the fraction is more than half, and the fraction will be simply omitted if it is less than half.

For further details, the reader is referred to the "Examples of Estimating," published at Roorkee.

SECTION VII.—BRIDGES.

CHAPTER XXIX.

TEMPORARY BRIDGES.

69. Before entering on the subject of Permanent Bridges, it will be useful to consider the temporary expedients which are so often resorted to, especially in India, for the passage of rivers and streams, where a want of time, money, or skill, prevents the employment of more durable methods.

The first of these temporary expedients are *Paved Causeways*. Many Indian water-courses, as will be explained further on, are dry, or nearly so, except during the rainy season. In some of the very dry districts of the North-West, the water-courses often contain no water for eleven months out of the twelve. The beds of such streams are, therefore, in general, passable without a bridge, but they require to have the banks cut down to an easy slope, and the bed of the stream to be paved for a sufficient width to save the labor of draft through heavy sand, or sand and water combined.

This paving must be laid strong enough to withstand the rush of water during freshes, and may be of brick or boulders set in mortar, or of concrete. The thickness of masonry in each case must depend on the nature of the bed, and the force of water when the river is in flood. To guard against scour and to save masonry, the depth on each side may be greater than in the centre, so that the roadway may be protected as by curtain walls.

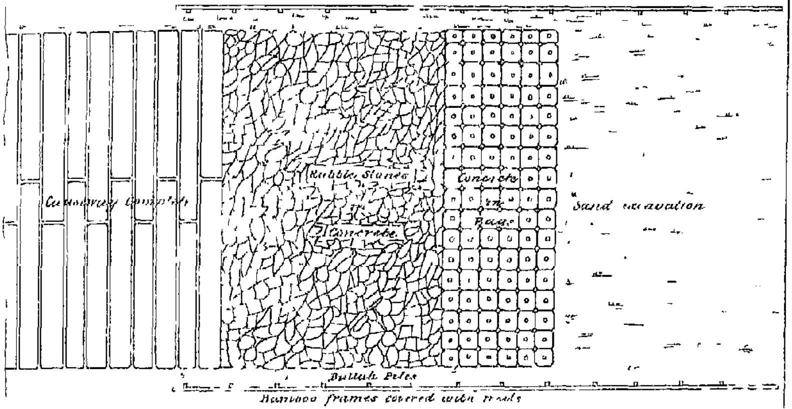
70. The following is a description of the Causeway across the Soane, where the Grand Trunk road crosses that river:—

> The distance from the western extremity or head of the causeway to the point where the Baroon bank of the river rises above ordinary floods, and the metalled Grand Trunk road again commences, is 11,450 feet.
>
> The line of the causeway having been marked out, common jungle *bullah* piles

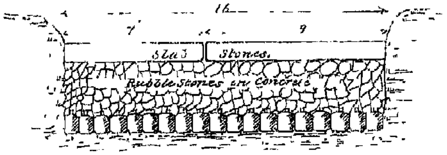
SOANE CAUSEWAY.

Plan of end of Causeway under Construction

Detail of Causeway



Transvere Section

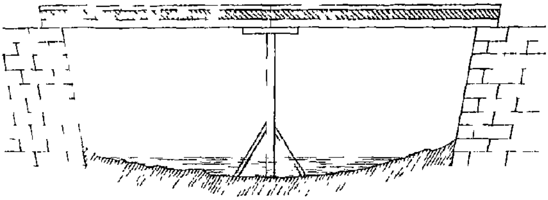


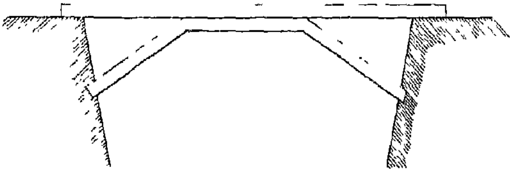
Total length of Causeway as proposed	11,450 feet
Done previously to 1860.	5,582
Do 1860–61.	9 '2

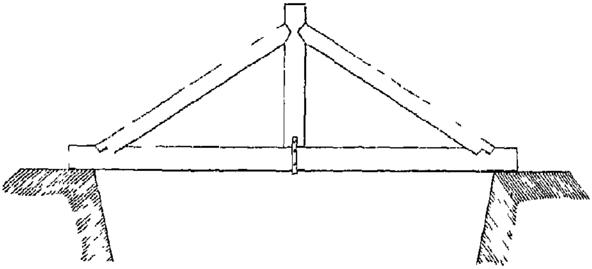
Scale

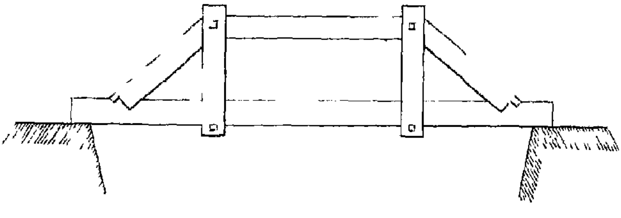
PLATE XVIII

TEMPORARY WOODEN BRIDGES









were driven in two parallel lines, at a distance of 17 feet apart, to a depth of about 15 feet; the sand having been excavated with shovels in the ordinary way. Between these piles down to the water level, or a little below, bamboo frames with palm tree leaf mats were forced down behind, to prevent the sand from the sides slipping into the excavation. The remainder of the sand below water level was excavated to the required depth by means of the ordinary well sinker's jham,* worked from temporary stages on either side of the excavation.

A layer of gunny bags filled with concrete composed of two parts Soane shingle, one part soorkhee, and one part kunkur lime, was then set as closely packed as possible over the whole bottom of the excavation.

Over this a layer, 2 feet 6 inches deep of rubble stone, set in concrete, of the same proportions as above is placed, and on this the roadway, formed of roughly cut stone slabs 1 foot thick, from 1 foot to 1 foot and 6 inches broad, and alternately 9 and 7 feet long, so as to break joint with each other, is formed; all irregularities of lower surface of the slabs being carefully packed up with rubble stone, the joints made as narrow as possible without actually dressing the stone, and thoroughly filled up, grouted, and pointed with the best kunkur lime and soorkhee hydraulic mortar; any considerable roughness and irregularities of the surface was then chipped down and levelled by stone-cutters; no attempt being, however, made at anything approaching fine dressing, the whole or any part of the surface of the stones, which would have been objectionable, as causing the road to be dangerously slippery.

71. *Temporary Wooden Bridges* may also be adverted to here as distinct from permanent timber bridges, which will be noticed further on. A few of the simplest forms are given, which may be made up by common carpenters and of almost any wood procurable.

Rope Bridges of various designs are used to cross mountain torrents which run between high steep banks in the hills. In some a single rope is stretched across the stream and made fast to trees on either bank; a sort of cradle in which the passenger sits, is slung on the rope and pulled across by means of ropes worked from either shore. In others the bridge consists of three ropes, one for the feet and two others for the hands of the traveller, kept asunder by triangular pieces of wood placed at intervals.

It is evident that neither of the above is suited for the passage of animals or vehicles.

Suspension Bridges of rope and bamboo are also in use. There is one of this kind near Calcutta 175 feet span.

72. We may next consider *Ferry Boats*, which are in use on nearly all the large Indian rivers, but are often replaced by boat bridges during the cold season. The boats are almost invariably those used by the natives from time immemorial, though these differ somewhat in shape on nearly every separate river. In general they are flat bottomed and very clumsy, and it is astonishing how seldom pains are taken to adapt them better to their special purpose, so as to be more accessible from the shores, when the water is shallow, to both animals and vehicles.

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* So specified in original, but the jhams used were much smaller and set at a less angle to the pole than those used in well sinking.—C. J. M.

The following is a description of a ferry boat used in the Bareilly district, which seems to answer its purpose very well:—

Two narrow boats, 50 feet long and 5 feet broad at the bottom, spreading out to 10 at the top, with fine sharp bows, are put 6 feet apart and joined together with well bolted beams. These beams, being covered with thick planks well bolted down, make a platform 28 feet square, which will carry a number of vehicles, animals and passengers. Towards the bow and stern are stiff railings, and on each side gang-boards (6 feet broad, and nearly the whole length of the platforms), which can be lowered to the land piers so as to admit of a carriage being driven on without unharnessing. These gang-boards when raised, which they can easily be with tackles, form high defences between the passengers and the river, on both sides of the platforms.

A paddle-wheel* 5½ feet broad, and 8 feet in diameter, turned between the boats in the after-part by two cranks, one on each boat, worked by eight men at each, or sixteen men altogether, will secure a speedy passage across, or it may be worked by a couple of men on board, by means of a capstan and cable, the latter having an end secured on each side of the river.

73. *Boat Bridges* are maintained over all the great rivers on the main lines of road from September till June, and occasionally all the year round where the stream is not too wide, or where it can be narrowed by the embanked road being carried forward on each side, so as to restrict the deep channel within reasonable limits. This might be done oftener than it is, if effected gradually in successive years, so as not to oppose the river too violently at first, and to give the earth-bank time to consolidate; and even if there were no immediate prospect of building a permanent bridge, it would make the passage far less troublesome, and improve the regimen of the river in readiness for a permanent work hereafter, though it would increase the difficulty of getting in the foundations.

To make a Bridge of Boats, the boats are anchored head and stern at intervals apart, and connected by balks of timber to support the planking of the roadway. No unequal boats should, if it can be avoided, be used in the same bridge; for as vessels of different magnitudes are immersed unequally by like weights, and the tops of their gunwales are not in the same plane, the floor of a bridge laid on them would be sunk unequally and out of level. If the boats be very capacious, though of different sizes, the difference of vertical immersion will be so trifling, even when the heaviest bodies are passing, as not to affect materially the stability of the construction, or require any particular precaution on account of unequal powers of floatation; but when small boats of different capacities are used in the same bridge, the intervals should be reduced, and regulated accordingly.

---

* The paddle wheel is covered in on both sides and above, and on the cover is the steering wheel.

In rivers exposed to much agitation from wind or floods, the construction of a floating bridge should be such as to allow something for the individual motion of each boat, so that the bridge may have sufficient flexibility to undulate a little with the swell, and thus yield to a force which might otherwise break or strain the beams. If beams, doubly keyed or bolted to each other, be prolonged, as if forming one piece, and rest on both gunwales of large boats, exposed by a heavy swell, to roll, or to rise and fall, it is evident that a force will be exerted to break the beams, if the motion impressed upon the vessels be too much restrained; and if, on the other hand, the beams be disconnected and laid from the side of one boat to the nearest gunwale of that adjoining, a small boat or vessel would dip, or heel, very much, under the pressure of any concentrated weight. To remedy this, a trestle should be fixed longitudinally in each boat, the upper surface of the ridge beam being raised a little above the gunwales, and the length of the trestle regulated by the intended width of the bridge. If the boats are large, and strong in the sides, the ridge-beam may be fastened upon beams laid across the boat; but if, as is often the case with keeled boats, the sides and timbers are slight though their bulk may be sufficient to displace the necessary volume of water without much immersion, the trestle should be raised upon the kelson.

The balks should be laid from trestle to trestle. The beams of all floating bridges should be nearly square, because, if the depth be much greater than the width, (as is the form in the construction of permanent buildings of timber,) they would be apt to turn on their side when the bridge is much agitated; and, would moreover, be deficient in lateral strength to resist the horizontal strains to which they may be exposed. The length of the balks is regulated by the distance the boats are placed asunder, and this again depends upon their size, their number, and the length and strength of the timber for beams. If the boats are large and strong, and good long beams can be procured, the intervals should be very considerable in a strong current, so that the water may be allowed to pass with as little obstruction as possible. If good timber sufficient to form beams of 8 inches by 6 can be procured, 20 feet may be allowed from trestle to trestle, and considerably more when vessels of 20 or 30 tons are used.

The boats nearest to the shore on each side being more particularly affected by weights moving on and off the bridge (on account of the slopes leading to the bridge from the banks, and the pressure thereby thrown upon the nearest boat), two of the strongest and most capacious vessels should be selected for the beginning and end of the bridge.

The width of the roadway depends on the amount of traffic. On any road of importance there should be a double roadway which may be separated by a centre railing. The greatest weight that can come on an ordinary roadway is that arising from a densely packed crowd of people, which is usually estimated at 120 lbs. per square foot, and the weight of the planking, &c., may be taken at 20 lbs. more. If the roadway were 18 feet wide and 20 feet long from boat to boat, the greatest total weight on the flooring of one bay would be 50,400 lbs., which divided amongst five balks would give 10,080 lbs. each, equal to 5,040 lbs. at the centre; if the beams were of sál, this would require a scantling of 8 inches square, though it would be better to make it somewhat greater.

The flooring should be 2½ or 3 inches thick, nailed diagonally across the beams, and covered with 8 inches of earth and stable litter. A railing of wooden posts connected by chains may be fixed on each side.

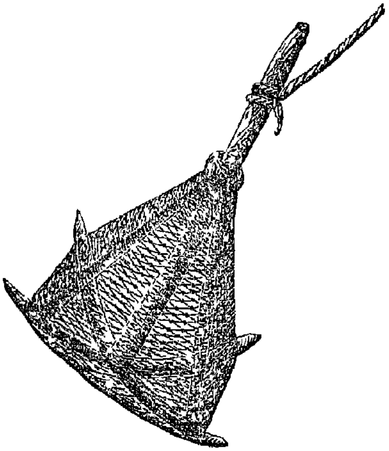
The balks are laid on the trestle in separate spaces, cleated off to receive them, and in which the beams work as the boats move in the water. The vessels are moored head and stern, and fastened together by pieces of timber lashed across the ends of the boats, to preserve the proper distances, and to save the balks from unnecessary strain.

When there is not sufficient depth of water to admit of boats floating within the proper distance from the river bank, and thus to form the two abutments, wharves, rafts, or trestles, should be constructed, and it is sometimes necessary to prolong these to a considerable extent into the river. For tidal rivers, or those which are exposed to be much swollen, and consequently to have their surface level suddenly raised, as in the vicinity of a mountainous country, the trestles used for this purpose should be formed of two strong upright pieces at each end, with a moveable ridge-piece, which may be raised or lowered at pleasure, and readily adjusted to any level, by iron pins, on which the ridge rests. In rivers subject to floods, the boats forming the abutment (and when the river bank is high, sometimes the two or three nearest boats at each end of the bridge) should each be fitted with elevating trestles of this construction, by means of which their ridge-beams may likewise be lowered, or raised, in due proportion, to give an easy degree of slope from the banks to the bridge, when these are so high, or the water so low, as to require the slopes to be thus prolonged.

It is indispensable to provide, in the construction of all floating bridges, for making, readily, an opening in that part which lies in the most rapid part of the current, so as to admit of the navigation of the river being opened, and of the passage of any floating bodies, which might otherwise endanger the bridge. The moveable part is constructed on two, and sometimes on three or more, boats, according to the magnitude of the river, and is formed into a separate portion, of length sufficient to fill exactly the requisite space. The beams of the moveable part project about 1 foot over the outside gunwales of the outward boat, the beams of the adjoining boats on each side, likewise project over their sides; and the ends of the beams are covered, so that they may not hitch in each other in reforming the bridge. The planks, or floor, are fastened down to the beams throughout the bridge by curb pieces, clamped down with wedges, except at the junctions of the standing and moveable portions, where the planks are attached to those adjoining them by hinges. The moveable portion of the bridge is provided with two large anchors, laid upwards in the stream, and a strong hawser is fastened to each standing end of the intended interval. The boats forming the moveable portion are likewise provided with rudders or steering oars, and windlasses. To open the bridge, the outside planks of the moveable and standing parts are folded back, to uncover the projecting portions of the beams. The wedges, by which the beams of the standing and moveable parts are clamped, are then driven out and the cables and hawsers eased off; when by the immediate descent of the moveable portion of the bridge in the current, an opening is quickly formed. The moveable part is then obliqued, by the influence of the rudders, to a convenient position behind either standing end. The method of re-forming the bridge is sufficiently obvious.

Where proper anchors are not available, wooden cribs filled with brick or stone, of the annexed pattern, may be used, and held by ropes or chain cables.

74. The following is a short description of the bridge of boats over the Jumna at Delhi.



During the rains the main stream of the river is 585 yards broad at the bridge of boats Seventy-seven boats and fifty-two double platforms constitute the bridge in the rains.

During the dry months it is necessary to bridge 513 yards, which takes sixty-six boats and forty-seven double platforms. The water covers but 178 yards, in which there are twenty-three boats and seventeen double platforms. The remaining 335 yards are sometimes dry, and sometimes under water, and in this part there are forty-three boats and thirty double platforms

There is a double roadway railed off on either side. Travellers and conveyances going from east to west are kept on one side, and those from west to east on the other There is a *pair* of platforms between the boats with a few exceptions. Only 18 boats belong to Government, the rest are hired at Rs. 10 a month each, for which the owner provides a boat and a *mullah* to each boat. Seventeen of the Government Boats were built in the Hills some years ago and cost Rs. 450 each; one boat was built in Delhi, and cost Rs 665; a pair of platforms cost Rs 144

75. *Pontoon Bridges* are superior to boat bridges for civil purposes, but their first cost is somewhat greater, and hitherto from the difficulty of getting iron work made up and want of transport, they have only been occasionally used in Northern India. A very excellent one has lately been constructed across the Ganges at Cawnpore, the iron pontoons having been made in the workshop of Messrs. Palmer and Co., at that station.

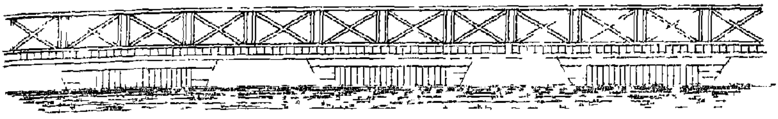
The following is a description of the one at Agra, which has been in use for many years.

The Agra bridge is supported on cylindrical sheet iron pontoons, the total length of the pontoons is 30 feet 8 inches; the middle part is 5 feet 8 inches in diameter, for a length of 22 feet. The ends are egg-shaped, the thickness of the sheet iron is $\frac{3}{16}$-inch, and the sheets are rivetted together with $\frac{1}{2}$-inch rivets, spaced from 2 to $1\frac{3}{4}$ inches apart from centre to centre. Each pontoon has a man hole, and a small hole for the mooring chain; the mooring chains vary, but are in general long linked chains $\frac{3}{4}$-inch diameter. No anchors are used, their place being supplied with blocks of stone

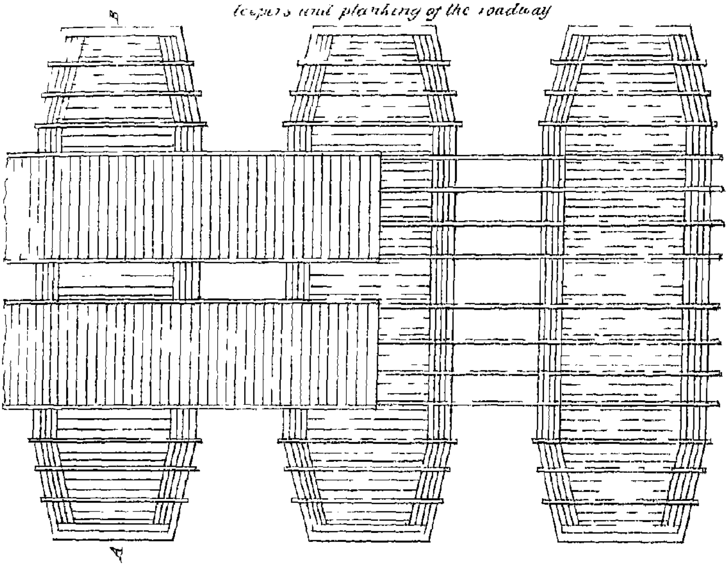
The pontoons are spaced 18 feet apart from centre to centre; on the pontoons, and

BRIDGE OF BOATS AT DELHI.

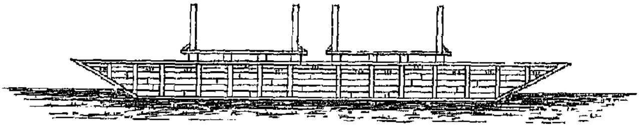
Elevation



Plan showing the arrangement of the keepers and planking of the roadway



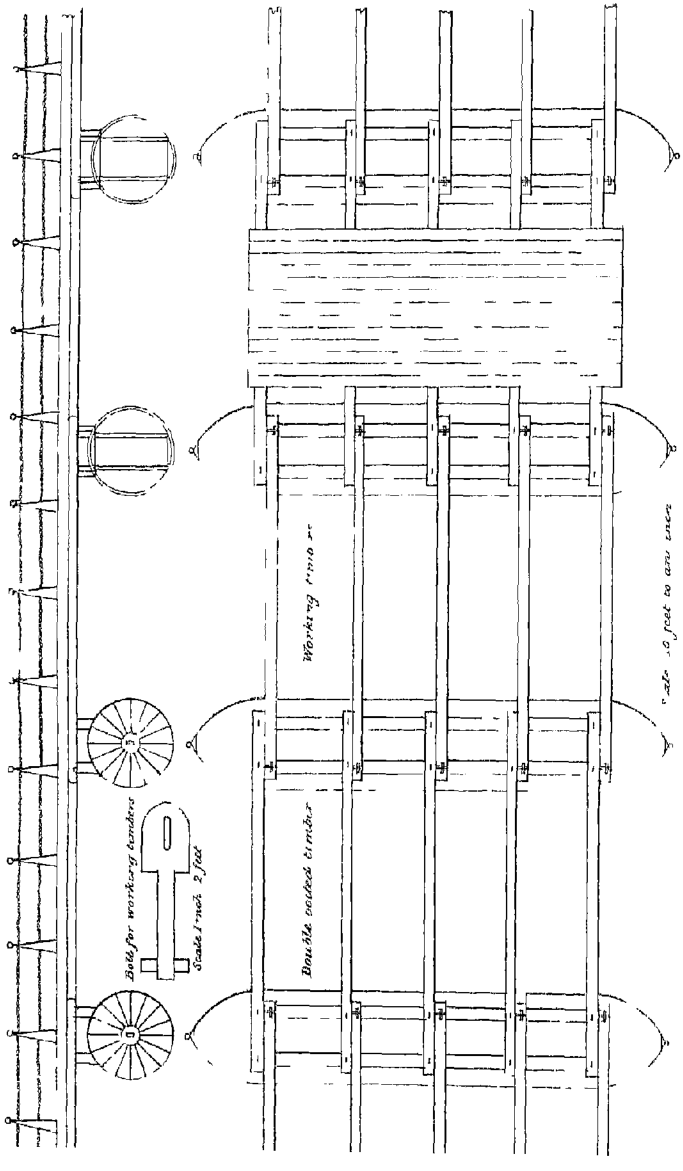
Section through A B, also of Roadway.



Length, . .	55½ feet
Centre Breadth,	17,
End Dº .	13¾ ,
Depth of Sides, . .	3½ ,,
Draught when loaded with roadway of Bridge	1½

PLATE XV

PONTOON BRIDGE AT AGRA

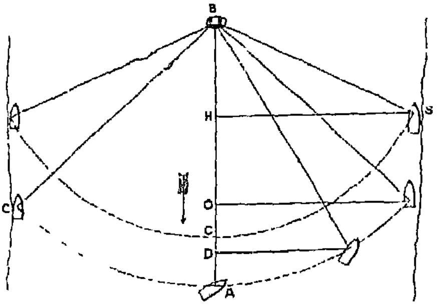


resting on a timber saddle, the longitudinal beams are placed, the two outside and the centre one being 8½ inches square, with four intermediate ones 8½ inches deep, by 5 inches broad, making in all seven beams; upon these beams, the planking, consisting of one thickness of 3 inches sál is placed. The width of this roadway or planking is 26 feet; it is spiked down to the longitudinal beams at each outside edge of planking. Both above and below runs a longitudinal stringer of sál, 7 inches wide by 2½ inches thick; this is bolted together with wrought-iron bolts; on the top of this, posts spaced 6 feet apart are stepped; between the posts run two lines of long linked ¼-inch chain. Inside the pontoons are placed props of wood to stiffen them.

To allow boats to pass up and down, there are two pontoons each 4 feet longer than the ordinary ones, on which are arranged two crabs with hinged platforms. These are raised, the whole removed to one side, and returned when the boats have all passed. The arrangement acts very well.

76. A *Flying Bridge* is formed by anchoring a floating body in a river, so as to receive the action of the stream obliquely, by which a force is derived from the current to move the vessel across the river.

The boat A (see figure), fastened by a cable to a buoy, B, securely anchored, will, in crossing from C, soon come into the line of direction of the current BD; and if she be steered in a proper degree of obliquity, she will pass through the ascending part of the arc to the bank E, whence she may be made to recross to C in the same manner.



The manœuvre will be more easily executed with a long than with a short cable, for it will be in the arc of a larger circle. If a short cable BG were used, the boat would have to ascend from G through a space equal to GH, to arrive at S, and consequently suffer great resistance from the action of the current. Also, resolving BS into BH, HS, we see that the force BH supports the boat against the stream, whilst it is held to the centre B by the greater force HS. The movement therefore should not be made in a longer arc than 90°; and when this rule is observed, the angle ABE never being above 45°, the force EO will never be greater than OB.

Whenever a long service of cable is used, it should be floated by intermediate buoys.

CHAPTER XXX.

PERMANENT BRIDGES.

PERMANENT Bridges are made of Wood, Brick, Stone, and Iron. The use of wooden bridges is in India, however, generally confined to places in or near the Hills, where wood is cheap and plentiful; they are, also, sometimes used in the plains as temporary structures, until time or money can be spared to erect permanent ones, but the destructibility of the material, and the liability of its parts to be deranged by the violent atmospheric changes common in the East, render its employment in general unadvisable. Before however the material can be considered, certain points require to be gone into which are applicable to *all* kinds of bridges. These are—1st, the Site; 2nd, the Waterway; 3rd, the Design.

77. *Site.*—When the place where a bridge is to be erected is not determined by the position of a road, which it is inexpedient to alter, the site which offers the most security for the foundations and the greatest economy in construction is to be preferred. If rocky foundations can be had, they will save much expense and anxiety; if not, any place where the river runs between high permanent banks will be good, as the river will not be liable to alteration, and the amount of water to be passed is easily known. In the plains of Northern India, however, even this cannot often be found. From the flatness of the country, and the vast quantity of silt brought down by the waters of an Indian river during the heavy freshes, caused by the melting of the snow in the hills and the periodical falls of rain, the bed is continually being raised, and the course of the stream perpetually altered. No one who has not watched one of these large rivers for some years would believe the extraordinary changes that occur in quick succession. Take for instance the Indus, above its junction with the other Punjab rivers. Its discharge in winter is 13,000 cubic feet, in summer at least 120,000. Its proper banks at the above place are 3 to 4 miles apart. Its cold weather channel in one year may be 1,000 feet across. In the next year in the

same place there will be three channels instead of one, separated by islands of sand. The ferry has often to be shifted two miles or more, up or down, in two following years. In four years it cut away 1½ miles of bank, measured perpendicularly, and threatened destruction to a large town. The next year the deep stream shot off to the opposite side three miles from the town.

It is evidently impossible except at an enormous expense to bridge the whole of such a stream as has been described, nor indeed is it necessary. What must be done is to provide waterway for the largest amount of water that can ever be expected to pass, and at such a velocity as shall not be dangerous, and then to connect the bridge with the high ground on each side by massive embankments carried across the valley of the river. For convenience sake the bridge might be built in the dry bed and the water turned through it when it was ready, it being an understood point that either the natural or artificial reach thus bridged should be as long and as nearly at right angles to the bridge as possible. It is also evident that the river should have as few assailable points presented to it as possible, *i. e*, that the piers should be few in number; which, of course, implies large spans. Hence is seen the great advantage in the employment of iron girder bridges. We can get in the foundations gradually during successive cold seasons; then proceed with the piers, and finally, with the superstructure, without having recourse to numerous centerings for turning a large number of arches at once, which are often surprised by the river, carried away and the stability even of the finished ones endangered by all not being completed. In fact, the difficulty of constructing arches of large span in brick and stone within a limited time is often practically insuperable, and with small arches great obstruction is caused by the numerous piers, so that by the time a large bridge has been finished, it has occasionally happened that the river has taken a new course altogether, leaving the bridge high and dry, and the water not to be brought through it except at a ruinous expense.

With large spans, the only fear is of the river carrying away the road embankments, especially when the earth is new, and they must be watched very carefully at every point across the whole valley, often many miles in extent. Their thickness must be great, they must be carefully made of rammed earth with a long flat slope on the water-side and well turfed, if possible. Moreover, the river itself must be well watched for some miles up-stream, and every exertion made to keep the stream straight and uniform in its new channel. Little can be done in this way when the river is in flood, but in the cold season much may be effected with comparatively small means if judiciously applied.

78. Though this subject properly belongs to the Improvement of Rivers, which will be treated of in a future Section, something may be said about it here. The chief maxim to be kept in mind is, that to turn a stream by direct opposition is almost impossible, while to *lead* it is comparatively easy, if we go to work in the right direction.

All subsidiary channels down which the water is inclined to run should be dammed across; for this purpose, sand dug from the bed of the river may be used, strengthened if necessary, by piling, or where the current is strong, old boats may be sunk. Meanwhile, the set of the stream should be carefully regulated, and any tendency to cut away its straight banks checked; and, for this purpose, fixed spurs or floating breakwaters are the most practicable means.

Spurs may be formed of a double line of piling filled in with brushwood, and carried out at an angle from the shore towards the current. The force of the water is checked where it impinges on the spur, a new direction given to the current and a considerable deposit of silt takes place both above and below the spur.* It is calculated that each spur will protect a length of shore five times its perpendicular distance from the bank down-stream, and three times up-stream.

Where the water becomes too deep and rapid to continue the spurs, floating rafts of wood may be fixed to their ends, and kept in the line by guy ropes fixed on shore, or by anchors. These floating break-waters may also be employed alone; they change the set of a current so long as they are in their places, but cause no deposit of silt, and are therefore not so effectual a remedy as the fixed spurs.

If the river succeeds in bursting the embankment at any point, the end of the breach should be defended by piling and spurs, so that the breach may be as small as possible, and advantage taken of the first subsidence of the water to close it. Every year the earth will become more and more consolidated, and finally, will be able to resist all the efforts of the water.

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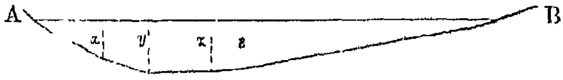
* The above means have been very successfully employed during the last two years in protecting the town and cantonment of Dera Ismael Khan from destruction by the Indus

In most cases of such rivers, it is a matter of indifference where the stream is crossed, but a careful survey of the proposed site should be made, and also of the water-course and its environs, above and below, accompanied by borings or trial pits, to judge of the nature and description of foundations that will be necessary.

79. *Waterway.*—The Engineer's next step after deciding where to cross, is to ascertain the amount of waterway which he must allow for his bridge, and very often this is a difficult task.

When the banks are well defined and the river does not overflow, then the question is comparatively easy; but when, as with most Indian rivers, in the dry weather they are mere rivulets, or perhaps nothing, whilst in the rainy season they become floods, spreading over the country, the question becomes one of intricate calculation, inasmuch as it is difficult to determine what portion of the water is moving and what is mere back-water. It is seldom also that the Engineer has opportunities of seeing the highest floods; therefore he gathers his accounts from others; or even if he should happen to witness a flood, he may not have means at hand of measuring the sections and velocities.

Let AB represent the flood line of a river; it is plain that if we measure the areas of each compartment x, y, z, and s, and ascertain with what velocity the water is moving through each, we shall know how much water actually passes by in a given time, say a minute or a second.



Now, as water flows by reason of the slope in a river's bed, if we know the velocities caused by certain slopes we can calculate what amount of opening would allow the whole of the water of the above section, to pass under a bridge at its mean velocity, and so avoid that heading up of the stream which, if carried too far, causes a velocity destructive to the bed of the river and so to the foundations of the piers of a bridge placed across it.

The safest width of opening would, in many rivers be inconveniently great; we are therefore obliged to run some risk by confining the floods to narrower bounds; and this causes a heading up or *afflux;* and in proportion to the perpendicular height of this afflux, will the velocity be.

The accompaning Table shows that sand is moved by the smallest velocities, even so little as 6 inches per second, or about one-third of a mile per hour, therefore, the beds of our rivers must be continually moving, and the question to be asked is, "to what depth does this river movement extend under certain velocities of current?"

	Velocity of river in feet per second.	Nature of the bottom which just bears such velocities.	Specific gravity of the material
Ordinary floods, ...	3·2	Angular stones, size of a hen's egg, ...	2·25
	2·17	Rounded pebbles, 1 inch in diameter, ...	2·614
Uniform tenour, ...	1·07	Gravel of the size of garden beans, ...	2·545
	0·62	Gravel of the size of peas,..	2·545
	0·71	Course yellow sand, ...	2·36
Gliding, ...	0·351	Sand the grains the size of aniseeds, ...	2·545
Dull, ...	0·26	Brown potter's clay, ...	2·64

Experience alone can be our guide in replying to the above question. Colonel Abbott calculated the velocity of the flood which destroyed the piers of the bridge over the Hindun at 11 feet per second, and the effect of this velocity was to scoop out the sand to a depth 25½ feet; it is plain therefore, that any velocity approaching to 11 feet per second, must not be risked in a river having a sandy bed.

Captain Sharp, in boring the bed of the Jumna at Agra, came upon broken bricks at a depth of 23 feet, and this can only be accounted for by supposing, that the bed has been disturbed to that depth by the natural current of the river confined by bold banks 1,300 feet apart. Captain Sharp judged the surface velocity at Agra to be 8 feet per second in high floods. Colonel Abbott calculated it to be not more than 6 feet per second, whilst he states the velocity of the greatest flood at Delhi at probably much less than 6 feet per second.

There can be no doubt that a velocity of 5 or 6 feet per second is dangerous to bridges whose foundations do not rest on firm soil, or which are not carried to very great depths. This may appear a small velocity to cause so much damage; observation has however afforded confirmation of the correctness of the assumption of this limit of velocity, under the arches of rivers with sandy beds, unless the foundations are carried down either to a hard stratum or to a depth of at least 40 feet.

80. The following Tables give the amount of afflux caused by obstructions in the river's course, and the velocity due to those affluxes can be calculated by the formula $v = \sqrt{2gh}$, h being the afflux, and g being equal to 32·17.

Amount of obstruction compared with the virtual section of the River.

Mean velocity of current in feet per second	1-10th	2-10th	3-10th	4-10th	5-10th	6-10th	7-10th	8-10th	9-10th	
	PROPORTIONAL RISE OF THE RIVER IN FEET.									
1	·0157	·0377	·0697	·1192	·2012	·3521	·6780	1·6094	6·6389	Ordinary Floods.
2	0277	·0665	·1231	·2108	·3548	·6208	1·1955	2 8378	11·7058	
3	0477	·1141	·2118	·3618	·6107	1·0687	2 0580	4·8850	20·1504	
4	·0760	1822	·3372	·5759	·9719	1·7008	3·2755	7 7750	32·0720	
5	1165	·2793	·5168	·8782	1·4895	2 6066	5·0202	11 9160	49·1535	Violent Floods.
6	·1558	3786	·9912	1 1807	1·9925	3·4868	6·7154	15 9398	65·7518	
7	·2078	·4983	·9221	1·5750	2 6578	4·6511	8·9578	21·2626	87·7080	
8	2578	·6423	1·1884	2·0299	3·4255	5·9917	11·5454	27·4012	113·0422	Unusually violent Floods.
9	3359	8054	1·4903	2·5566	4 2956	7·5172	14·4777	34·3646	141·7511	
10	4119	9877	1·8726	3 1218	5 2680	9 2190	17·7557	42·1440	173·8440	

EXAMPLE —The breadth of the Thames is 926 feet. The sum of the waterways, old London Bridge was 236 feet. The amount of obstruction, therefore, was about ·75 of the entire section; so that a velocity of 3½ feet per second would give a fall of nearly 4·75 feet, agreeing with the actual result.

If therefore the section of the river and its velocities can be accurately measured, the amount of waterway in the bridge, so as not to cause a greater velocity than 5 feet, nor a greater afflux than 5 inches, can be easily ascertained.

81. In order, therefore, to determine the required waterway for a bridge over any stream:—First, determine by enquiry the height of the highest flood ever known and correct the information, if possible, by flood marks. Then take an accurate section of the river's bed perpendicularly to the course at the site of the proposed bridge, and calculate the area contained between the highest flood line and the bed. Do the same at points one mile above and one mile below the proposed site of the bridge.

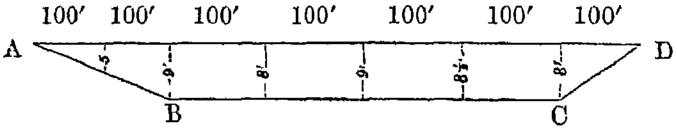
Measure the length of the undulating line of the river's bed in each cross section, and divide each area by this length; the quotients will be what is called the *hydraulic mean depth*, which will be found to vary very slightly from the common mean depth, in most Indian rivers. Add together the three mean depths so found, and divide by three, the quotient will be the mean of the three "hydraulic mean depths," to be used in the calculation: write it in inches.

Ascertain by means of a levelling instrument, the difference of level between the river bed at the upper and lower section; that is, the amount of slope in the river for two miles; and write it down in inches.

Multiply the hydraulic mean depth in inches by the difference of level just found (also in inches), and take the square root of the product, which will be the *surface* velocity (v) of the current, per second, in inches. The *mean* velocity (V) may be found from the formula, $V = v - \sqrt{v} + \frac{1}{2}$, which is, approximately $V = \frac{9}{10} v$, when the velocity is greater, and $\frac{8}{10} v$, when the velocity is less, than 3 feet per second. Algebraicably expressed, $V = \cdot 9 \sqrt{ds}$, where

V = mean velocity.
d = hydraulic mean depth.
s = slope of the bed per mile.

82. Suppose the following figure to represent the mean section of the three taken:—



The area of this section is 4600, and if the length of the line ABCD measure 710 feet; then 4600 ÷ 710 = 6·48 feet, the hydraulic mean depth.

Let us suppose that the two other mean depths were 6·8 feet and 6·1, then $\frac{6\cdot 8 + 6\cdot 1 + 6\cdot 48}{3} = 6\cdot 46$, which is the working hydraulic mean depth; and in inches it will be 77·52.

Say that the difference of level between the upper and lower sections is 30 inches; then, $\sqrt{77\cdot 52 \times 30} = 48\cdot 2$ inches, which is the average surface velocity, and $48\cdot 2 \times \frac{9}{10} = 43\cdot 38$ inches, or 3·6 feet mean velocity in feet per second.

Suppose it had been proposed to force the stream under three arches each of 50 feet span, springing at a height of 9 feet above the bed of the stream, then 3 × 50 × 9 = 1,350, is the area of the proposed waterway, and this is nearly three-tenths of the whole section, therefore the obstruction will be seven-tenths. A reference to the above Table will show that this would cause an afflux of 3 feet for the above velocity of 3·6, which would give a velocity under the bridge $= \sqrt{2g \times 3} = 13\frac{1}{2}$ feet per second, which would wear away anything but the hardest rock.

83. Having the mean velocity of the natural waterway, that of the artificial waterway may be obtained from the following expression:—

$$v = \frac{S}{s}\,Vm,$$

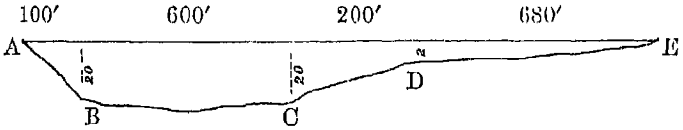
in which s and v represent, respectively, the area and mean velocity of the artificial waterway; S and V the same data of the natural waterway; and m a constant quantity, which as determined from various experiments, may be represented by the mixed number 1·045.

Thus in the given case, to find the waterway s, corresponding with a given velocity of 5 feet per second,

$$s = \frac{V}{v}\,Sm = \frac{3\,6}{5} \times 4600 \times 1{\cdot}045 = 3461,$$

which, divided by 9, the height of the piers, gives 384 for the length of waterway required, or 8 arches of 48 feet each.

The formulæ and co-efficients used above are however adapted only to rivers, the outline of whose section is a nearly regular figure, which is seldom the case with Indian rivers in flood. They are capable of being modified however, so as to suit the circumstances of the case; thus, if we suppose a river to have the following section:—



The area of the whole is 15,800 square feet, the hydraulic mean depth is 10·5 feet or 126 inches. Suppose the fall in two miles to be 10 inches, then $\sqrt{126 \times 10} \times \frac{9}{10} = 31{\cdot}95$ or $\times\ 2{\cdot}66$ feet, and $15{,}800 \times 2{\cdot}66 = 42{,}028$, is the discharge in cubic feet per second, according to the general rule.

But if we take the section in two parts, viz., ABCDd as one, and the triangle EDd as the other, and calculate them separately, we shall find a considerble difference between this result and that of our first computation, thus—

The area ABCDd = 15,200, the hydraulic mean depth is 16·6 feet or

199·2 inches; then $\sqrt{199 \times 10} \times \frac{9}{10} = 40·162$ inches, or 3 316 feet; and $15,200 \times 3·346 = 51,059$ cubic feet per second, as the discharge for the one portion alone.

The triangular portion has an area of 600 square feet; the hydraulic mean depth is 1 foot, or 12 inches; then $\sqrt{12 \times 10} \times \frac{9}{10} = 10$ inches nearly, the superficial velocity. And $600 \times \frac{10}{12} = 500$ cubic feet, the discharge per second; therefore, $500 + 51,059 = 51,559$ the discharge, instead of 42,028, as in the first computation.

84. The maximum surface velocity of the current at any point may also be ascertained by the simple process of allowing a cork or other light *float* to be carried along by the current of the middle thread of the watercourse, and noticing the time of its passage between two fixed stations. From the velocity at the surface, ascertained in this way, the average, or *mean velocity* of the water, which flows through any cross section of the waterway between the stations where the observations are taken, may be found by taking *four-fifths* of the greatest velocity measured at the surface. This is a method commonly pursued in practice, the breadth of the stream being divided into a certain number of portions, and the surface velocity in *each* being ascertained by separate observations.

In taking the discharge of the Indus some years ago, I proceeded as follows. The point selected was where the river was in one channel about 1,000 feet across. Ten country boats were used and provided with anchors of the pattern shown at page 60.

Two flags were set up opposite each other on the two shores and in a line at right angles to the stream, and the boats being hauled up-stream, were dropped down one by one and anchored at intervals by signal from the shore. Their positions were marked by measuring a base along the shore and taking angles to each boat. The depth was then taken at each boat, and between every two by a moveable boat, and the velocities ascertained by floating a cork along a marked length of 20 feet at each of the fixed boats. Of course this was an irregular and only approximate section, but in such a river and with such a current it is very difficult to get a regular section taken at exactly equal intervals. In a stream of less strength a rope with distances 50 or 100 feet apart marked on it might be stretched across, and anchored at two or three points, and the depths and velocities taken at each interval by one boat hauled along the rope from mark to mark. The *Current Metre* is also used for ascertaining velocities; it is a small brass wheel which is put into the stream, and has an index to measure the times of rotation in any number of seconds, as shown by a stop watch.

85. In making a new road across a line of country which crosses any important drainage lines, it will not be sufficient to calculate the discharge of the water-courses by the above methods, as it will be impossible to say how far that discharge may not be increased by a raised road preventing the rain water running over the country, and forcing it into the water-courses. It will be necessary to calculate the area of the basin drained by each water-course, usually termed the *Catchment Basin*, and cross levels must be taken at intervals where it is possible, to show the breadth of the basin. Its length will be the length of the stream draining it, from the point where it emerges from the hills. At this point, the highest discharge must be taken as above, and the highest quantity of rain-fall in 24 hours over the area of the basin being known or assumed,* the sum of the two may be taken as the greatest quantity of water that ever passes. Part of this will be lost by evaporation and much by absorption, depending on the nature of the soil and slope of the country—the remainder will have to be provided for in any bridges that may cross it. The data for evaporation and absorption are very vague, and therefore no certain rule can be laid down for the Engineer, but the following emperical formula has been deduced by Col. Dickens, R.A., from a comparison of certain practical data, and until a better one is known, may be used as an approximate guide.

Let M = the number of square miles of drainage area of any river or water-course, no matter how small.

Let D = its discharge at highest flood, in cubic feet per second.

$$\text{Then } D = 825\,M^{\frac{3}{4}}.$$

Or in logarithms—

$$\text{Log } D = \log 825 + \tfrac{3}{4}\log M.$$

This formula is, of course, only applicable to cases within a certain average of annual rain-fall—say of 36 inches in the year. It may, however, be considered to hold approximately to all cases from 24 to 50 inches of average annual rain-fall; as the heaviest fall of rain varies less in proportion than the *total annual rain-fall.*

To make use of this formula it is necessary, first, to have the usual data of sections, transverse and longitudinal, of the river's bed. Then determine by a few trials the flood level which would give the discharge required by the formula. This may be compared with the reputed flood level. If they differ materially, the latter should be again investigated. After this it will be safe to adopt whichever determination gives the highest flood level.

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* Usually, 12 inches for India.

For small drains, it will be quite safe to fix a velocity such as the soil will bear, and allow waterway enough to discharge the heaviest flood as determined by the formula from the drainage area.

The following Table, computed on assumed velocities, and assumed proportions between depth and width of streams, shows, in a general way, the results of this formula in determining the size of bridge necessary for a given drainage area.

Drainage area.	Discharge, cubic feet per second	Assumed velocity, feet per second.	Square feet of waterway.	Bridge for common cases		
				No of spans	Span in feet.	Height of piers or abutments
1 acre,	6½	5	1½	1	1½	1
2 "	11	5	2¼	1	2	1⅛
3 "	15	5	3	1	2	1¼
5 "	22	5	4½	1	3	1½
8 "	31	5	6	1	3	2
16 "	52	5	10½	1	4	2½
40 = $\frac{1}{16}$ sqr. m.	103	6	18	1	6	3
⅛ square mile,	173	6	29	1	7	4
¼ "	292	6	49	1	10	5
½ "	490	6	81	1	12	7
1 "	825	6	137	2	12	6
2 "	1,388	7	200	3	12	6
3 "	1,881	7	270	3	14	7
5 "	2,760	7	400	3	16	8
7 "	3,550	7	507	3	18	9
10 "	4,640	7	663	3	20	11
20 "	7,804	8	975	5	20	10
30 "	10,577	8	1,322	5	24	11
50 "	15,605	9	1,734	5	30	11½
100 "	26,094	9	2,899	5	40	14½
200 "	43,884	10	4,388	7	40	15½
300 "	59,481	10	5,948	9	40	16½
500 "	87,255	10	8,725	9	50	19
1,000 "	146,737	10	14,673	15	50	19
2,000 "	246,780	11	22,434	15	60	24
3,000 "	334,487	11	30,408	20	60	25
5.000 "	490,636	12	40,886	20	75	27
10,000 "	825,000	12	68,750	30	75	30
20,000 "	1,387,746	13	106,749	40	75	35
30,000 "	1,870,962	13	143,920	45	80	40
50,000 "	2,695,690	14	190,256	50	90	42
100,000 "	4,639,274	15	309,285	60	100	50

86. *Design.*—Under ordinary circumstances the nature and design of a bridge, great or small, will be influenced by the nature of the material procurable, the skill of the workmen, the amount of money to be expended, &c., as well as the nature of the river to be passed.

At present iron structures are practically out of reach of the ordinary Engineer, as they have to be procured from England, and as the objections to wood have been noted, and even good stone is not often procurable, his choice will often be limited to brick.

After the foregoing calculations the Engineer is in a position to determine of how many spans or bays his bridge is to consist. If the stream is gentle, its bottom not likely to be disturbed, and the foundations not likely to be troublesome, and if his materials are not good and his workmen unskilful, he will probably choose a number of small arches. If the river be one as above described, subject to great floods, the bottom liable to erosion, and the foundations likely to involve great expense, he must procure good workmen and have few bays of large span, the superstructure being of Iron or Wooden Trussed Frames, or Arches of Brick or Stone, which we shall have to consider in order.

CHAPTER XXXI.

MASONRY BRIDGES.

87. *Definitions.*—The portions of the roadway at each extremity of the bridge which lead to it are termed the *approaches*. The extreme supports of a bridge, by which it joins the banks of a river are termed the *abutments*, and the intermediate supports of the arches are termed the *piers*. The walls which sustain the embankments of the approaches, where they join the bridge, are termed the *wings* or *wing-walls*. The faces of the bridge up and down the stream are sometimes called the *head walls*. The projections of the piers beyond the faces are termed the *cut-waters* or *starlings*. The centre line of a bridge between its extremities is termed the *axis*. The under side of an arch is called the *intrados* or *soffit*; the former term being used when large arches, like those of a bridge, are spoken of, and the latter for small arches, such as usually occur in buildings. The outside of an arch is called the *extrados* or *back*. The two lowest extremities of an arch are called its *springings* or *springing* lines. A line extending from the springing line on one side of an arch to the springing line on the opposite side, is called the *span of the arch*. The *crown* of the arch is the part most remote from the springing line, and the parts of the arch for a certain distance up each side from the springing lines are called the *haunches*. The *spandrils* are the spaces contained between the extrados and a horizontal line from the crown. The *blocking course* is the portion of the side-walls between the crown of the arch and the bottom of the parapet.

88. *Foundations* of piers and abutments must be on soil sufficiently firm to bear the weight of the superstructure and obviate any chance of settling, and deep enough to be safe from the action of the water, increased as that action will generally be by the obstacle presented by the piers. The beds of all Indian streams are generally sandy, and the foundation must be carried through down to the firm soil below. Care must be taken also that this firm bed is of a good depth, for sometimes it may be a mere thin

stratum of clay or gravel between two strata of sand; the borings will show this. In a gentle stream a bridge of moderate size would stand well on 3 feet of firm clay, the lower courses of the foundation being just let into the firm soil below the sand, but a large bridge should have not less than 6 feet of clay. Very often the depth of sandy soil is 10, 20, or 30 feet, and though when not exposed to the action of water, sand is not a bad foundation, yet it is liable to be moved even by the most gentle current, and in Indian rivers subject to floods, it is often torn up or worked into deep holes by the stream. It therefore becomes necessary to seek artificial means of securing the foundations.

With small bridges, and where the current is not very strong, and where the natural waterway has not been much diminished by embankments, it is sufficient to support the bridge upon "boxed foundations." These are formed by making large boxes of wood of the shape of the pier, but about 9 inches or 12 inches larger each way as to length and breadth. The boxes have neither top nor bottom, their sides vary in height from 6 to 10 feet, according to circumstances. These boxes are driven into the sand by scooping from the interior and they are then filled with rubble masonry. Upon this the piers are built. These boxes are in fact small coffer dams and the water can be excluded from them by hand pumps, or scooping. If the execution of ordinary masonry is troublesome from the presence of water, the foundations may be made of concrete, composed of broken stone or brick and hydraulic mortar in the proportion of 7 to 1. Another plan is to build the bricks into large blocks and when dry let these down, and join the blocks together below. Below the depth of 10 or 12 feet, however, it is better to resort to *Piling* or *Well-sinking;* or one or other of the means which have been described in Vol. I., Chapter XV.

89. In large bridges with the foundations on wells, it is in general unnecessary and undesirable to have a masonry *flooring* between the piers, as the soil is unstable, and anything that tends to obstruct the water from passing as usual through the bays, may cause a scouring action on the river's bed. The Madras Engineers, however, almost invariably use a flooring protected by curtain walls, only sinking their foundation wells 6 to 10 feet deep. The curtain walls are sunk both up and down-stream from pier to pier and to the same depth as the pier wells, the flooring being of concrete, or brick-on-edge, 2 to 4 feet deep. This construction is undoubtedly cheaper at first than the Bengal method, owing to the great cost of sinking deep wells; but it is often necessary to secure the down-stream end of the flooring from the action of the water by continually throwing in rough stone until the action has ceased; and where a large supply of loose material of this kind is not available, it would generally be necessary to continue the flooring for some distance down-stream, and to secure its tail by another curtain wall. The cost of this addition will often equal the difference between the cost of shallow and deep wells, and the latter are certainly safer in Bengal rivers, where the sand is of a semi-fluid character.

Both systems should be fairly considered by the Engineer in the particular case before him, and the preference given to one or the other, according to the circumstances of the case.

90. *Piers.*—As the horizontal thrust of the two half arches on each side of a pier, counteract each other, the only effort that the pier will have to sustain will be that arising from the weight of the two half arches, with the additional weight that may be placed over them up to the road surface. The thickness of the piers at top need therefore, in theory, be only sufficient to sustain this pressure, and each square foot of brickwork being calculated to bear a weight of 80,000 lbs., or 35 tons, without crushing, a pier 2 feet thick would suffice to carry arches of 100 feet span, and 4 feet thick; but this is much less than what is given in practice, for allowance must be made for injury by time and corrosion to the exterior surface of the piers, for shocks from floating bodies, for inequality of thrust in the arches either from difference of span, or of workmanship.

The ordinary dimensions for brick piers are one-sixth of the span for arches from 15 to 30 feet, one-seventh from 30 to 60 feet, and one-eighth for larger arches. This thickness is measured at the top of the pier.

In bridges composed of numerous arches, it is sometimes advantageous to make every fifth or sixth pier strong enough to act as an abutment, as the arches can then be turned in sets, and if not all completed in one season, the remainder may be safely left till the next, and afterwards should one arch give way, the damage would not extend further than to the next abutment pier, but when no abutment piers are built, the fall of one arch may be followed by that of all the others.

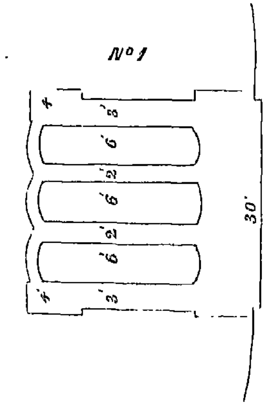
When all the arches of a bridge are not built in one season, a small temporary arch may be turned on one side of the last pier, (supposing it not to have been made of extra abutment thickness,) to support a portion of the next arch, and act as a counterpoise to the last of those finished; or if the stream can be turned from this pier, a heavy mass of brick in mud may be built up against it as a buttress, and also on the top of the pier so as to add to its weight and so resist the thrust.

Short piers should be built with perpendicular sides, but a very high pier looks better for a batter of about 1 in 12. Piers for semi-circular and semi-elliptical arches whose extrados and intrados are parallel, are finished with flat tops, but for segmental arches, and arches whose extrados are segments of circles, the tops must be fashioned to the angles of the springing lines with *rubbed bricks*, or with bricks moulded for the purpose, and they are then called *skew-backs* or imposts.

Piers, as well as abutments, having to sustain a great pressure should, be very carefully built with very good bricks, and very fine joints, to obviate unequal settlement.

91. *Abutments* having to sustain the thrust of the end arches unbalanced by the counter thrust of any adjoining one, require to be thicker than piers; and as the thrust depends on the span, rise, and weight of the arch, this should be calculated before determining the thickness of abutment to be given in any particular case, instead of merely assuming for the thickness some fixed proportion of the span.

No 1



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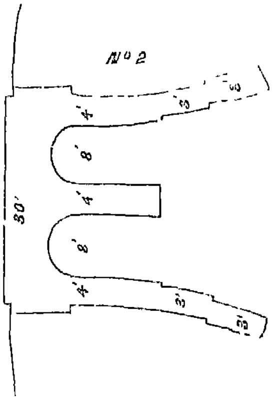


At the same time it is to be remembered that if the wing walls and buttresses of an abutment are built up, and the filling in of earth behind it is carefully executed, simultaneously with the building of the main abutment wall,—the whole mass increases the resistance to the thrust of the arch which is eventually to come upon it. Abutments more frequently give way from settlement of their foundations than from insufficient thickness.

The back of the abutment should be built up to a height of one-third of the rise of the arch above the springing line, and the half spandrels filled in like manner as above the piers.

The above are good forms of abutments in combination with wing walls.

The calculation of the necessary thickness of the abutment to resist the thrust of the arch has already been investigated in Vol. I., Chapter XIV.

92. *Arches* of stone and brick bridges, are either semi-circular, segmental or semi-elliptical (the curve in the latter case being either a true or false ellipse).

Semi-circular arches are strong, and have the advantage as well as those truly elliptical, of exerting no thrust upon the piers. But they generally give too great a rise, thereby involving heavy and expensive approaches. The elliptical arch gives the greatest waterway for a given area and is very light and graceful in appearance, but is not so strong, and is more difficult to construct than the segmental, which is the curve usually adopted.

The proportion of rise to span in an arch varies from about one-seventh to one-fourth, the ratio increasing with the span. The young Engineer had better refer to the numerous examples of bridges on record as patterns to enable him to determine this in each particular case, remembering that the flatter an arch is, the more care is required in the workmanship, and the higher it is the more expensive are the approaches. The springing of the arch should be somewhat above the level of the highest known flood, and if the river is a navigable one, there must be room also for a laden boat to pass easily under the arch at high flood level.

It is now most usual to give the same rise and span to all the arches of a bridge and to place their springing lines on the same level. This is perferable to having arches of unequal dimensions, with their springing lines lower in receding from the centre to the extreme arches. When the first plan is adopted, the parapet wall and roadway will be on the same level throughout, and measures must be taken for keeping the latter dry by apertures at the bottom of the parapets. The latter plan has however the advantage of reducing the cost of the approaches by having a gradual fall in the roadway from the crown towards the two ends, and many think it quite as picturesque as the other.

The proper *Thickness of Arches* has been investigated in Chapter XIV.; where also the rules for laying out the arch are given.

The *Bond of Arches* has also been treated of in the above Chapter; but it may be as well to say that as both the methods given in para. 255, for brick arches are to a certain extent defective, when the work is of importance and the cost can be afforded, the common bond should be used and carried right through the arch. One brick is laid on edge to the centering, its length laying in the direction of the breadth of the arch; the next brick is placed with its end upon the centering and its length in prolongation of the radius; thus breaking joint on the thickness as well on the breadth of the arch.

93. *Spandrells.*—The spandrells or spaces between the arches may be filled up in various ways, but the following are considered the best. In small bridges the masonry having been brought up to a level with about one-quarter of the rise of the arch, is then sloped up to the top of the crown and the remaining space filled up with gravel or stone-rubbish, but not with sand or clay. In large bridges the best mode of filling up the spandrells is to build cross-walls between the arches founded upon the solid masonry already mentioned, and increasing in length as they advance in height; they rest upon and abut against the backs of the arches and act as struts between them. These walls are placed from 2 to 3 feet apart, and are made from 18 inches to 3 feet in thickness, according to their height. They are bonded together, if of considerable height, by laying long stones, or when stone is hard to get, long flat tiles of earthenware occasionally across from one wall to the other. The outside spandrell walls, sometimes called *face walls*, running parallel with these, are connected with them in the same way and become a part of the general frame. The walls are carried up nearly to the crown of the main arches when the spaces between them are themselves arched over. Openings are made at the bottom of these walls along the top of the piers, through which any water that may fall into, or by any means be collected in the spandrells, is conducted to one point and issues through a pipe or spout placed for that purpose. The outside spandrell walls are usually made thicker than the interior walls, and a wall should be built along the piers and abutments crossing and binding the other walls. When the spandrells have been brought to the proper height, they are dressed to the slope which it is proposed to make the roadway, which is recommended to be not greater than 1 in 24.

In designing the spandrells it should be remembered that the tendency of a very flat arch is to fall in at the crown, and that to counteract this tendency, a certain amount of weight is allowable and even beneficial on the haunches. On the other hand the tendency of a high arch is to open out at the crown, and to prevent this the haunches should be lightened as far as possible. From not attending to these two principles, bridges are constantly designed with an amount of masonry altogether unnecessary, and a very needless expense is thereby incurred.

On the top of the face walls comes the *blocking course;* this course of masonry extends the whole length of the bridge along the arches, spandrells, and wing walls. The upper course of it should be of sufficient breadth to allow of an inner and outer projecting ledge, as well as space for the foundation of the parapet. The upper side of the outer projecting ledge or cornice should have a slope or weathering to throw off the water, and be properly throated so that the water shall not trickle down the face of the bridge.

In some large French bridges the spandrells have been filled up entirely with rubble masonry, but this throws an unnecessary weight upon the arches. To remedy this, small arches have been made quite through and kept open, or sometimes concealed; and in the Westminster and Orleans bridges, vaults have been constructed to lighten the piers which sunk and those adjacent to them; but as these arches are easily deranged by any settlement of the main arch, and by that means rendered injurious rather than beneficial, the mode first described is considered the most simple and the most effectual.

94. *Wing Walls.*—The wing walls may either be built at right angles to the abutment, or with a curved splay outwards; the first plan is the simplest and has the advantage of giving a better hold to the earth of the river banks; but when the road narrows on crossing the bridge, or when two or more roads meet at the approach to it, the wings require to be curved. When the soil of the river banks is bad, the foundation of the wings must be laid at the same depth as that of the abutment for their whole length, otherwise unequal settlements and cracks are likely to result from the height and weight of portions being unequal. But if the soil forming the banks of a stream be firm, the wing walls may be cheaply and strongly built with foundations in steps corresponding with the form of the banks. The depth of each successive step should be determined with reference to the section of the bank and to the soil; in rocky ground the surface of each step should be 2 feet below the surface of the ground, and in gravel 3 feet.

A good rule for the length of wing walls is that they should be one and a half times the height of the roadway above the bed of the river. Their thickness at bottom may be one-fourth of their height, and they should be built with off-sets on the inside so as to reduce the thickness at top to 2 or 2½ feet. In fact, the rules for their thickness are the same as for other retaining walls, and the thickness of wing walls should depend not only on their height but on the description of the soil; when that is firm and compact there will not be so great a pressure on the wings as when it is loose. Wing walls of very great thickness have been thrown down, or cracked to such an extent that it has been necessary to rebuild them, from the earth having been thrown in loose between them and swelling after becoming saturated with water. This accident would never happen if the precaution were taken of filling in the earth gradually, as the walls are being raised: it is then trodden on daily and cannot afterwards be easily penetrated by water. When abutment walls are built with long buttresses the pressure on the wing walls is decreased.

The ends of the wing walls are always widened so as to form pillars of support which may be square under ground, and of any form above ground which may be considered most appropriate to the design of the parapets to which they form terminations.

95. *Parapets.*—The height of the parapet wall above the roadway may be 3 feet in medium sized bridges, and may be increased in larger ones to 4 feet, while for small road tunnels a few inches will be sufficient. The thickness may be either a brick and a half or two bricks, the former will generally be sufficient.

On the interior side at bottom there should be a projection 4½ inches square, called a *wheel-guard*, when there are no foot-paths, to keep off the cart wheels. This should be of stone if procurable, otherwise of brick-on-edge.

The blocking course on which the parapet is built, should be from 1½ to 2 feet wide, and 1 to 2 feet high. The inside of the parapet should be quite plain, as any projecting ornament would be quickly knocked off: on the exterior side, at top and bottom, a neat cornice will improve the appearance of the bridge. Should a balustrade be adopted instead of the ordinary parapet wall, it should be formed of bricks moulded expressly for that purpose; hollow pottery ballusters should never be used.

Perforated parapets of various designs may be built with bricks specially moulded, and they have the advantage of lessening the accumulation of dust on the road. The architectural finish of the bridge must be left to the taste of the designer. The following hints may however be useful. All ornaments for a bridge should be bold and massive; a full projecting cornice with but few members—a panelled parapet with curved coping. The directions given to the cappings of the pier heads and the indication of form of the intrados given by projecting the arch face a few inches beyond the the face walls, and chiselling them in voussoirs, and a similar projection of the ends of the piers, are the principal means whereby a pleasing architectural effect may be produced.

If the parapets are more than 5 yards long, holes should be left at intervals on the sides of the bridge close to the parapets and through the parapets of the wing walls. These holes are for the purpose of letting the rain-water drain off the road. The drains may be carried either through the crowns of the arches or through the piers, obstruction is least likely to occur in the former; or the drainage may pass over the face walls through holes under the parapets. The bottom of the holes should be about an inch below the level of the road surface, and if there is a cornice, the water should issue above it.

Brick bridges are almost invariably plastered. The principal objection to the practice is that the brickwork is likely to be less good in consequence, and the parapets soon present a shabby appearance. A stone coping would be more secure from injury, and would very much improve the appearance of a brick bridge left unplastered. The courses of brick work would then have to be laid with regularity, and with thin mortar joints well pointed; the requisite cornices and other ornaments could all be executed in bricks, either chiselled or moulded to the form required.

96. *Roadway.*—The first flooring of a bridge should consist of a layer of brick-on-edge, and on this a layer of good kunkur well rammed down to 1 foot at the crown and 9 inches at the edges, even if the roads leading to it are not metalled. This should never be omitted, and the rubbish from the brick-kilns should be taken for the purpose, if no better material is procurable.

A curbing of stone or brick-on-edge should then be laid about 4 feet from the parapets for the footpaths, which may be laid with paving stones or large flat tiles. The footpaths should be raised 3 or 4 inches, a sloping or saucer drain being made between the curbing of the footpath and the carriage way on each side. The curbing and sloping drain should be of stone when procurable.

Four granite guard stones are required to be fixed in the road, either at the extremities of the parapet or at the parts where the roadway begins to narrow, to protect the parapets from cart wheels. All small road tunnels should be made the full breadth of the road, whatever that may be; but from motives of economy, the breadth of the roadway over bridges may be reduced in places where the traffic is little to 18 feet, but in all high roads it should be 27 feet, and in large cities as much as 36 feet; these breadths are exclusive of the thickness of the parapets, and are multiples of 9, which is the space required for the passage of a carriage conveniently, and without risk of collision. Footpaths may be gained on either side overhanging the face walls, either by bricking out or by supporting them by cast-iron corbels.

When the roadway over a bridge is much higher than the country adjacent, sloping approaches may be necessary. They should not be steeper than 1 of rise to 30 base. If the bridge have but one arch, or arches of equal height at the crown, the roadway over it should be nearly horizontal, the slopes increasing on reaching the abutments. If the arches are of different heights, the thickness of the roadway over each of them at the crown must be the same. These precautions are requisite to prevent unequal loading of the arches. A perfectly level roadway over a bridge is less easily kept dry, than one with an inclination both ways from the centre. By forming the road with a slight convexity in its cross section, with a slope also lengthwise, most of the water falling on a bridge will run along the gutters between the road and the footpath on each side. This water should be conducted beyond the end of the wing walls, and there introduced into pucka drains, carried in the most convenient direction to the low ground.

97. *Stone Bridges.*—In large Stone Bridges, strong and durable stone, dressed with the chisel or hammer, should alone be used for the masonry of bridges of large span. The interiors of the piers and the backing of the abutments and head walls may for economy be of good rubble, provided great

attention be bestowed on the bond and workmanship. The bond of cut stone in ashlar masonry is arranged like that of brick work, so that the stones may everywhere break joint; the greater the weight of each block the stronger will the structure be. In all bridges where large stones are used, a crane has to be employed to raise and lower the stones into their places. Where the masonry is exposed to violent shocks, the stones are not merely bonded but are jointed together, and iron cramps are used to strengthen them still more. This, however, principally applies to masonry exposed to the violence of the waves. Rubble stone masonry is very common in this country, made of irregular blocks or stone as taken from the quarries, or of large boulders found in the beds of hill streams. In the latter case the stone should be broken with the hammer so as to give a rough surface for the mortar to adhere to. The bed is prepared by spreading over the top of the lower course an ample quantity of good mortar into which the stone is firmly imbedded. The interstices between the larger masses of stone are filled in by thrusting small fragments of stone into the mortar. Finally the whole course should be carefully grouted before another is commenced, in order to fill up any voids between the full mortar and stone. The courses should also be carried up horizontally. To connect the parts well together and to strengthen the weak points, *throughs* or *binders* should be used in all the courses, and the angles should be constructed of cut or hammered stone.

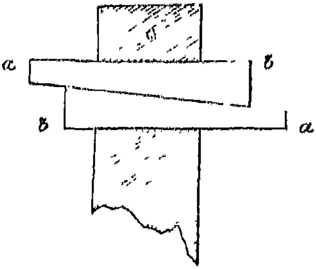
98. The temporary supports required during the construction of arches are called *Centres* or *Centerings*, and their construction for small arches has been described in Vol. I., para. 253.

Similar centerings with three or more ribs are applicable to road tunnels, and may be made into lengths of 10¼ feet each, the lagging being nailed on to each rib and extending over at least two spaces; the joints, if any, being alternate, so as to hold the whole frame work well together. In building the drain or tunnel, the centering is first to be fixed in its proper place, at one end of the work, and the arch is then built over its whole extent. That done, the centre is *struck* (which is the technical expression for releasing and taking down centering) and it is moved forward very nearly its own length, taking care to leave 3 inches of one of its ends underneath, but in contact with the underside of the portion of arch that has been built. In this new position, it is to be made straight and level, and again fixed; when a second quantity of arch work equal to its length may be built upon it, when it is again struck, advanced, adjusted, and fixed, and is ready for a third length of work; and by this process, a tunnel may be *continued any required distance with only one short* centering. Two or three centerings of this kind will be found very useful, when a large number of tunnels of the same span are to be built on a new line of road; where, however, wood is dear and carpenters scarce, a solid centering of earth may be formed, by filling in between the side walls or abutments with rammed earth, and then forming a raised surface of the same to the shape required. This mould is to be removed by digging out, after the tunnel is completed, or so far as completed at any time.

For bridges of large spans, the centerings most in use in India are those with intermediate supports, as shown in Vol. I., Plates XXIV and XXIVA., which have also been described in para. 253. In rivers subject to sudden freshes, it will be advisable to build the lower part of the centering pillars of brick in lime mortar, or at least to point them with such mortar, or the mud cement getting soft will be compressed by the superincumbent weight and cause cracks in the arch.

When the span is more than 30 feet, it will be advisable to adopt *a centering, composed of four or five timber frames constructed upon* horizontal tie-beams supported in several places by brick pillars, from the top of which struts should radiate to support the main ribs in as many points as may be requisite. These main ribs are to be preserved from lateral movement by cross struts and braces, and the irregular polygon formed by them must be brought to the form required for the arch, by supplementary frame work of slighter construction, under the lagging.

99. *Striking Centres.*—When the arch is finished, the temporary supports have to be *removed and for this* purpose several methods are used, which have to be provided for in the design and construction of the centering. The most usual way is by means of wedges placed under the wall or pillar plates, by the striking of which on their sharp ends, the wall plates may be gradually lowered. These being double it is evident that if their small ends, *aa*, are struck inwards the line *ab* will be lowered, and with it the wall or pillar plate *c*, and anything supported by it.



Wedges should be in sets of three; the middle one directly under the weight supported, the other two at equal distances on each side of it; then by striking the centre one first, the weight will be equally supported by the two side wedges, the centre one being refixed loosely, the side wedges may be struck till the weight is again borne by the middle wedge, and thus the lowering may be safely and gradually effected.

The wedges over each pillar should all be struck equally and simultaneously, but as this is difficult of accomplishment, it may be sufficient if the wedges are struck in succession, lowering slightly those in the centre line first, then those in the two next lines, and so on to those at the springing, taking care that the lowering is very gradual and equable.

In order to avoid the necessity for sending men in under the arch to strike the centerings, the wedges may be connected together on beams so as to pass outwards from the two centre frames or trusses to either end of the arch; striking each beam inwards lowers every centre frame resting upon it. In centerings entirely supported at the springings of the arches, four such beams, or two on each side, only will be required. In centerings on pillars, two will be required on each row of pillars, between the pillar plates and the trusses. In small arches these beams may be driven inwards with mallets, but in large arches the work may be done by a beam mounted and worked as a battering ram.

The wedges should be made of hard wood, and the beam above should also be hard and smooth; if a rough timber is placed on the top of a badly formed wedge, there will be the greatest difficulty in getting the latter to move at all, they should be thoroughly cleared of dirt and rubbish, and be well oiled before the process of lowering commences.

A still more gradual method of lowering centerings was used in constructing the Roorkee aqueduct, viz., by the introduction of jack screws in the place of the wedges prior to lowering; this was effected by the use of triple wedges, the middle wedge being struck out without affecting the centering; its place being then supplied by the screw tightened up to receive the strain, the outer wedges were then struck away and the pressure left on the screw. The screw being well oiled and fully up to the work required of it, could be turned by means of a long iron lever so as to lower the centering almost insensibly. A row of these screws might, as in the case of the beams with wedges cut upon them, be connected together, so as to work entirely from outside of the arch. With good centerings, however, and well turned arches, little danger is to be apprehended in standing under the largest and heaviest arch, whilst the centering is being lowered; it is rather common coarsely built arches or centerings, brought to the form required by heavy masses of brick and mud, from which danger is to be apprehended, and in these cases, wedges connected together so as to be struck from the outside should always be used; or better still, such arches should never be built at all.

The wedges are also sometimes placed immediately under the lagging, and being thus more numerous, each bears less weight, and can therefore be moved with more ease, and, consequently, with more certainty; so much so that the centering may be lowered in parts and accidental distortion of the arch by that means sometimes rectified.

100. But by far the best mode of lowering the centres of bridges is by means of Sand-boxes or cylinders, which is thus described by Captain Fowke, R.E., in his Report on the Paris Exhibition of 1855:—

"One of the most interesting points in connection with the construction of this bridge (Pont de l'Alma) is the method employed for striking the centres by means of cylinders filled with sand. The employment of this method does not produce the slightest change in the construction of the centering itself, as the cylinder is simply substituted for the wedges on which the centres are supported. The apparatus consists of a cylinder of wrought-iron, 12 inches in diameter and 12 inches high, which is placed in a vertical position on a wooden platform, on which it is prevented from slipping by a circular piece of wood, three-fourths of an inch thick, nailed to the platform and fitting the interior diameter of the cylinder. Near the base of the cylinder, at four equidistant points of its circumference, are bored holes 1 inch diameter, which are stopped by corks introduced from the interior of the cylinder, which is then filled to within 2 inches of the top with sand previously dried and passed through a fine sieve; and into the space thus left is fitted a solid piston or plunger of wood, coinciding exactly with the interior diameter of the cylinder, about 10 inches high; the whole apparatus which is thus about 20 inches in height, is then introduced under the centres in lieu of wedges; and M. Bouziat, by whom this method has been invented and applied, gives the following account of the process of striking the centres:—

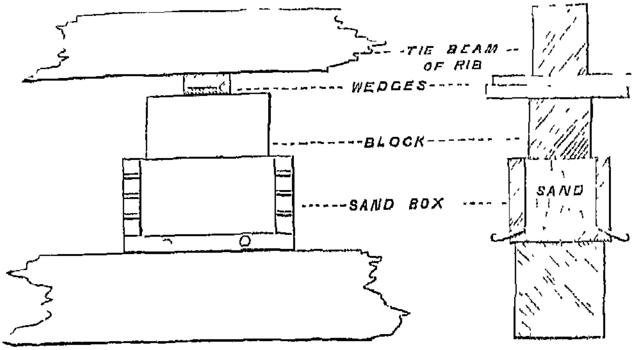
"'In striking centres, at a given signal the corks closing the orifices in the cylinders are withdrawn by an iron rod about a foot long and 0·31 of an inch in diameter, pointed at one of its extremities and flattened and turned up at the other. The sand then issues slowly until it has formed a little cone opposite each hole, and stops. When everything is ready the Engineer gives the order to lower from 2½ to 2 inches; then, by means of the iron rods, the men remove the cones of sand, and help its escape with the curved end in the event of its having got wet during the progress of the work, until the piston shall have descended the distance required, which will be noted by a scale attached to each piston. The workmen then allows the little cone of sand to accumulate and waits for a fresh signal, and in this way the centre descends gradually, and detaches itself uniformly from the arch without shaking it. It will be seen that being completely master of the operation, leisure is given to make all necessary observations, so as to be assured that all goes on well, or to take measures should the contrary be the case. At the Pont d'Austerlitz, commenced the 20th May, 1854, and opened for traffic on the 8th November, the centres were struck in two hours, and it might have been performed in still less time by placing a man to each of the cylinders, so as to lower all the centres simultaneously Each arch of the bridge was supported by 36 principals, and the enormous weight of both the masonry of the arch, and the metal of the roadway, bore on the centres, they not having been removed until after the opening of the bridge to the public.' "

101. This method has been lately much adopted in India, and the following are examples of its application in particular instances *(Professional Papers, Vol. I.)* :—

"Many of the bridges on the Mirzapore district are built with ashlar arches of 60 feet span and of great weight, necessitating a very strong centering; this consisted generally of seven ribs of sál timber, carrying for laggins a layer of the sleepers, afterwards used in the permanent way. The ribs were kept vertical by being tied together with cross braces, and were supported with four pairs of wedges under each rib in the usual way.

"The centering of our first arch was struck in the old way; a man with a sledge-hammer was placed over each pair of wedges and at a given word they all struck together. From that moment the noise of the hammers rendered any further order inaudible, and the wedges came out one after the other, in no particular order, according to their tightness or the strength of the hitting. The result was most unfortunate; the heavy ribs came down singly, and in so doing broke from the cross ties, and ultimately fell over on their side and severely injured some of the hammermen.

"It was this accident which caused the adoption of sand boxes, which were made in the following way:—



The box is made of 2-inch sál plank, 18″ × 9″ × 9″ inside dimension; the sides are dove-tailed into the ends and the joints all secured with 5-inch screws; the top is left open. Over this box and resting on the sand is a rectangular block measuring 16″ × 8″ × 8″, so as to give half an inch play at each side and one inch at the ends. At each side of the bottom of the box are a couple of 1-inch holes sloping upwards and inwards, and closed for the time with wooden plugs loosely driven in and luted round with a little moist clay.

"When the arch is ready for striking, four of these boxes, (28 in all,) are placed under each rib as near as possible to the supporting wedges, the box filled with dry sand, the block laid carefully on the sand so as to be clear of the inner edges of the box, and a pair of greased wedges with only 1-inch taper are driven with a hand hammer between the block and the tie-beam of the rib. The old wedges are then easily knocked out and the arch rests on the sand and is freed by drawing out the plugs.

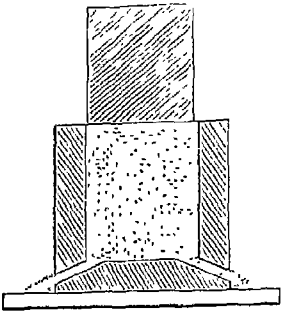
"The same set of boxes was used for sixteen arches without receiving any material damage.

"This construction of sand-boxes may perhaps appear too simple to be worth describing, and the only feature to which I wish to draw attention is that the surface of the sand is left uncovered for half an inch all round the edges and shows no tendency to overflow, notwithstanding the enormous weight laid on it, it being the property of sand not to transmit lateral pressure beyond a certain angle.

"The central surface of sand on which the block is laid forms such an unyielding bed that in transferring the weight of the arch and centering from the old wedges to the sand-boxes, the greatest subsidence observed at the crown was never more than one eighth of an inch.

"The play thus allowed to the block is essential to its steady descent, because as the sand is let out by the sides, its upper surface does not remain horizontal, and the block being no longer on a level bed would, if made to fit tight, most inevitably get jammed and stop or burst the box; any close fitting plug or piston will I think be found to fail on this account.

"I would suggest the following modification of the above construction as applicable to very large spans, or to any case where the arch requires to be let down slowly or the process of lowering to be stopped at any point.



"Dispense with the plugs and let the box stand on a plank a foot wider than itself so as to form a shelf 6 inches wide under the plug holes; thus the sand from the holes will stand on this plank in small cones at about 30° to the horizon, and will stop the holes as effectually as a plug. By sweeping these cones away with the hand, the sand will escape and the centering may be lowered with any degree of slowness; by letting the cones stand the process may be stopped. By the same means one part of the arch may be lowered quicker than another, which is sometimes advantageous when cracks occur in unexpected places.

Morhur Bridge, Bengal.—Six arches of 74 feet span. The centres were designed with double longitudinal beams, the lower one carried on the posts and struts forming the supports of the centre, and the upper one forming the tie to the series of triangles, forming the upper portion of the centres (*vide* Plate XXIII., Vol. I.) This upper beam rested on the lower at a distance of 12 feet through blocks 8 × 8 × 12 inches of soft easily splitting wood (*dhow*). When the arch had been keyed, a strong sack made of double coarse country canvas (*tat*) made as a tube, filled with dry sand and tied with string at both ends, was introduced between these two beams close to each block, a plate of stout plank (12 × 15 × 2 inches) being placed above and below to distribute the pressure fairly over the bag; and finely tapered wedges in pairs were driven between the upper plate and the upper longitudinal beams with heavy mallets, until the weight of the centres in lieu of resting on the blocks, was borne by the sand bags, and the blocks were so far loosened that they could be easily driven out of their places with a few blows of the mallets. Any individual blocks which could not be thus relieved, or were jammed, were split out by carpenters, but this was not found necessary in more than two or three cases. The blocks were then re-introduced into their places, but laid on their sides instead of on end, thus leaving a space of 4 inches between their upper surfaces and the lower side of the upper longitudinal The whole centres now rested on the bags, of which eight supported each truss, or forty the complete centre. Eighty ordinary coolies were now brought up, two to each bag, (one taking charge of each mouth,) and two or three Europeans posted among them to see, and report, each order obeyed. The word was then successively given—*First*, to untie the up-stream mouths of each bag but not to allow any sand to escape; *second*, to untie the down-stream mouths; *third*, to allow the sand to run out of the bags, when the whole of the centre sank gradually and steadily until it again rested on the blocks placed to receive it, leaving the arch unsupported.

It was really a very pretty sight to see the large mass of complicated timber framing 74 × 24 × 16 feet, and weighing nearly 50 tons, besides the portion of the weight of the arch of masonry resting on it, gradually subside, with a motion so slow and smooth that it was perfectly unnoticeable even while standing on it, except by the separation between the lagging and the arch, and the approximation between the longitudinal beams; so uniform was the motion, that not even a creak was heard from any joint of the frame, and the time occupied by the movement did not exceed one minute. The amount of sinkage at the crown of the arch was accurately noted by means of two heavy leaden plummets weighing 8 to 10 lbs. each, and having a small brass scale attached, one of which was hung from either side of the crown by an iron wire, and rested in a tub of water below to check any oscillation of the plumb-bob; consequently the depth to which the scale was immersed before and after striking, being carefully noted, the difference showed the exact amount the crown of the arch had sunk; this measurement was further checked in some arches, by observing a point on the key of the arch from a distance, through the telescope of a theodolite.

102. Various periods have been laid down as proper to allow between the keying and the uncentering of arches, though it has been generally agreed that immediately after the completion of the arch, the centerings should be slacked a little so that the bricks may close in and compress the mortar. And certainly this should be done before the facing, spandrel, and outside parapet walls are built upon the arches, because a trifling change of form in the arch may occur by its settlement without impairing its strength, but which might crack and disfigure the external face walls; but if they are not built until the arch has taken its final set, there will be no danger of their being afterwards deranged or disfigured. Arches have been safely uncentered immediately after keying and have changed their shape but slightly; centerings have also been left up one and two months, and even six months, and though on their removal, the arches have not sunk at all, yet they have done so occasionally after the addition of the weight of the superstructure. It is clear that any change of shape in the arch must be less prejudicial to its strength, while the mortar is soft, than after it has set, for, should any settlement *then* take place, the work must become crippled.

When, however, a large arch has been built on a solid centering, or one that cannot be properly and equally lowered, it may be requisite to allow the arch to set, at least partially, before proceeding to remove such a centering, which, moreover, has probably allowed by its compression, of some degree of settlement in the arch.

103. In illustration of the foregoing paragraphs, a few examples of Indian Masonry Bridges actually constructed are appended; from *Professional Papers, Vols. I., II., and III.*

Sohan Bridge—Lahore and Peshawur Road.—The area drained by the Sohan at the site of the bridge is about 573 square miles, and is very compact in shape. The greatest depth of the river in floods is 15 feet, and the mean velocity about or 9 feet per second. The slope of the bed is at the rate of 14 feet per mile. The calculated mean velocity is 13 feet per second. The discharge calculated from cross sections of the stream is in extreme floods about 91,000 cubic feet per second, which is equivalent to about one-fourth of an inch over the entire catchment basin. The bed of the river exposed to view, consists of boulders ; water flows all the year round, and is never less than 1 foot in depth. The true bed of the river is the hard red clay of the country, over that a layer of blocks of conglomerate, and over that some 12 or more feet of boulders.

At the site selected for the bridge, the river is rather wide, being over 1000 feet, while a few hundred feet higher up the width does not exceed 750 feet. (*See* accompanying plan.) The clear waterway of the bridge is 945 running feet.

The design consists of 15 spans of 63 feet each, entirely of masonry and the bridge is floored throughout.

Specification.—The foundations to rest throughout on the clay bottom of the river. The masonry below the flooring to be of coursed rubble, the faces not to be dressed. The floor to consist of large blocks of stone well fitted, and the end stones to be of the largest size and cut to fit closely.

From the floor to the spring of the arches the masonry to be of the best coursed rubble in large blocks with dressed faces. The imposts to be accurately cut.

The arches, spandrel walls, and superstructure of parapets to be of best brick-work. The cornice to be of cut stone. The surface drainage of roadway to be discharged through the crown of each arch, by an iron pipe just clear of the wheelguard.

The entire surface of the roadway to be metalled with broken stone.

The stone to be used is sandstone, from the quarry on the Leh Nullah, and none but the very best quality of stone is to be put into the work.

Estimated cost, Rs. 4,28,271.

Markunda Bridge, Punjab.—During the floods of the rainy season, the river has a depth of 6 to 9 feet. From observations and surveys made in 1859, the following discharge of the river during flood was obtained. The observations were made about 3 miles above the site of the bridge, where the banks of the river are well defined.

Width of channel,	1,577	feet.
Area,	6,938	,,
Rate of fall,	3.72	feet per mile.
Mean velocity,	5·15	,, per second
Discharge,	35,730	cubic feet.

In 1845, a flood rose 18 inches above the bank of the river, giving a discharge of 47,838 cubic feet ; nothing approaching to this has occurred since.

The Government of India, gave the following specific instructions for the preparation of the design.

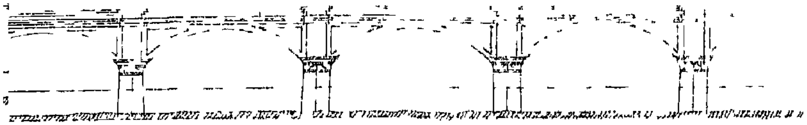
The width of the roadway to be 26 feet, the depth of the pier foundations to be limited to 15 feet, and that of the curtains to 12 feet.

The bridge to be divided into five sections by abutment piers.

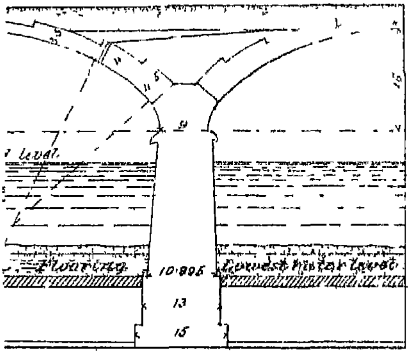
The waterway not to exceed 1,073 running feet.

The nature of the foundations of the bed of the river was examined, but nothing but sand, or at best, a clayey silt, was met with, to a depth of 40 feet.

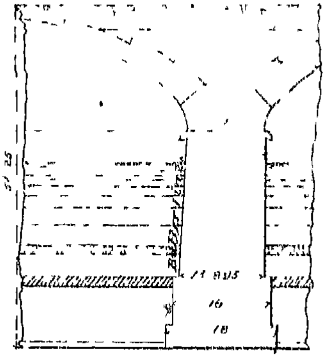
The total length of the bridge is 1,400 feet, and the height of the roadway above the bed of the river is 24 feet.



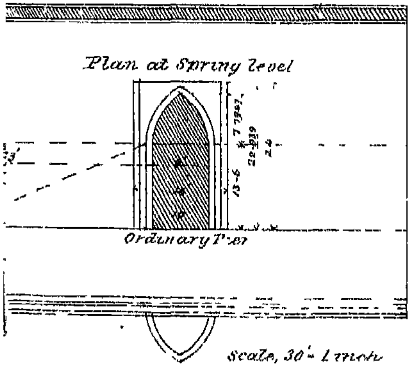
ngitudinal Section (Enlarged)

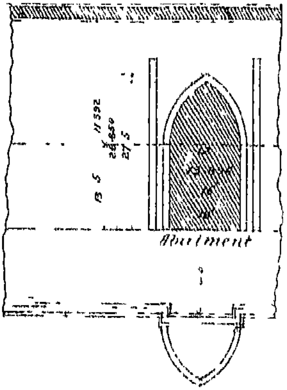


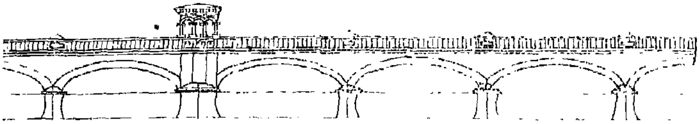
Abutment Level

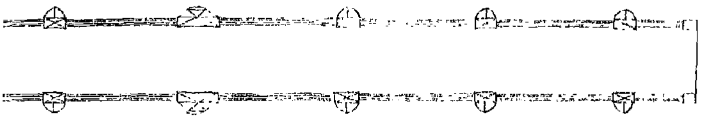


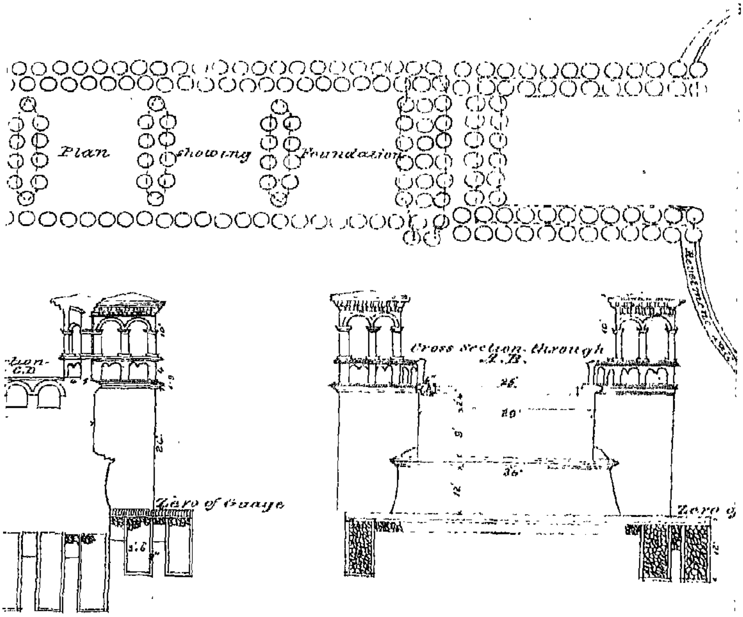
Plan

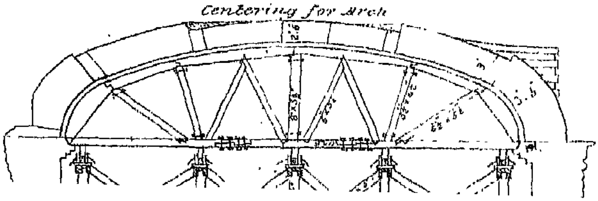









Plan showing Foundation
Cross Section through A.B.
C.D
Zero of Gauge
Zero o
25
30
36
12
9
12
5.6


Centering for Arch
2.6
3

Specification.—The curbs for the wells to be made of keekur, tallee, jamun, or other sound jungle wood; they will be 9 inches in thickness, put together in threes, and firmly secured together by wooden treenails of seasoned keekur wood. The masonry walls of the wells are to be 9 inches in thickness, and are to be built of radiated bricks, moulded or cut to the proper form, and laid with mortar composed of two parts of soorkhee, to one part of freshly slaked stone lime, burned on the works, and well mixed together in a mortar mill in the usual manner.

All bricks used in the work are to be soaked for at least six hours previous to their being used, and the masonry is to be kept moist, to prevent the too rapid desiccation of the mortar, until the mortar gives indications of setting. The walls of the wells are to be carried up 6 feet, and allowed to dry for at least ten days, when the undersinking may be commenced.

The whole of the wells of one pier or abutment, are to be undersunk together; when the wells have been sunk 3 or 4 feet, then the walls may be raised 6 feet more; when the wells have been sunk 8 feet, then the walls must be weighted with kucha pucka masonry, to facilitate the undersinking, as well as to prevent the walls parting from the curbs.

When the wells for the curtain walls have been sunk to their full depth, the excavation for the concrete, which is to be laid between the wells of the piers, (as shown on the drawing) as well as for the concrete beneath the flooring is to be commenced.

As soon as a well has been sunk to the required depth, it is to be filled at once with broken brick to the required level. In laying the concrete, 6 inches is to be laid and consolidated at a time, water from the foundation having been removed by pumping.

In undersinking the wells, the old system of jhams and divers will be dispensed with as much as possible; pumps will be used to keep down the water in the well, and ordinary excavators will be employed, the material being brought up by means of a bucket and windlass; when the material at the bottom of the well is slush, the bucket is to have a valve in its bottom so as to fill itself.

In the piers and abutments, the bricks will be laid in English bond, with half-inch joints, and grouted every course.

As the work advances, the hardest and best shaped bricks will be set aside for the arches. Each arch will be divided into several portions, by joints running completely through from soffit to back, the bricks being laid in those successive portions, alternately in rings and blocks, with joints running entirely through the arch, from soffit to the back. English bond will be used in the portion laid in rings, the thickness of the arch being divided into two equal rings; the blocks in which the joints run through, are not to exceed four bricks in thickness, measured on the soffit. Great care will be taken in laying the bricks which form the keys of the arches; thin tempered mortar or grout being used, and the joints well wedged up with hard pieces of brick; in keying in the arch, the first course on the soffit will be formed of a thickness of three bricks laid on their ends, in very thin mortar; the next course will be formed of five bricks, laid also on end, and forming continuous joints with those below them; this course will be laid in grout. By dividing the length of the course into several compartments, separated by a single row of bricks, laid in mortar, the grout may be poured into these compartments, and the bricks be set in it, and the joints then filled with pieces of brick.

The haunches of the arches will be carried up and allowed to set before bringing up the remainder of the arch. Care must be taken to load the crowns of the centres to prevent springing.

The arches will be turned on regularly framed timber centres; these will be supported by timber struts; each point of support will be capped by a strong wooden pillar plate; on this will stand a cast-iron cylinder fitted with a wooden piston. The cylinder will be 9 inches in diameter, of sheet iron, in thickness $\frac{1}{16}$-inch and 12 inches in length, open at both ends. It will have 4 half-inch holes; at half an inch from the lower end of the cylinder, these holes will be fitted with four wooden plugs so that they may be pulled out and inserted by the hand; each cylinder will have a solid wooden piston fitting it freely, and of the same length as the cylinder; the cylinders will be filled to 3¾ inches of their length with clean sand, on which the wooden piston will rest. When it is desired to strike the centering a man will be stationed at each cylinder; at the order being given, they will simultaneously pull out every man his four plugs; the sand will be allowed to run out until it forms a sort of semicone on the pillar plate opposite each hole, when the sand will stop running until the sand outside be cleared away; on which, it will run again from the cylinder, and so on; care must be taken that no moisture finds its way down the sides of the pistons at the cylinder.

The centres will be slightly eased immediately after keying the arch, but the centres are not to be *struck* until six weeks at least have elapsed after the keying in; a longer time will be allowed if convenient.

The mortar to be used on the work is to consist of one part of freshly burnt stone lime, and two parts soorkhee made from pieces of pucka bricks, and ground in a mortar mill in the usual manner; that used for the face joints to be ground in a hand mill.

The concrete will consist of the following proportions:—

1 part of stone lime.
3 parts of soorkhee from pucka bricks.
6 parts of broken bricks, kunkur or stone, two-thirds of which not to be larger than a hen's egg.

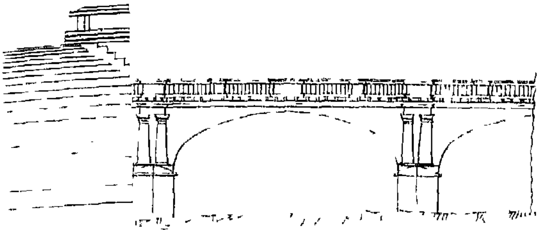
The concrete to be mixed together in a little tank close to the work and thrown in from a height; no plaster will be used on any portion of the work.

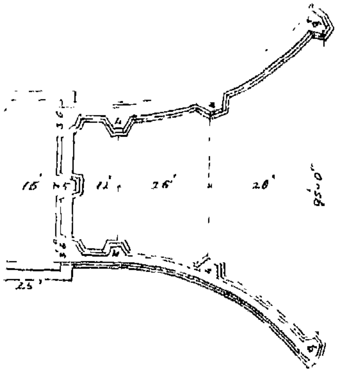
Estimated cost, Rs. 3,61,180.

Ganges Canal Bridges.—Some of the details of their construction, are only applicable to Canal bridges, and there are no two of them exactly alike, but a general description will be useful, as the whole of the bridges on this Canal may be said to be excellent specimens of brickwork.

The first-class bridges consist of three arches of 55 feet span each, with piers 7 feet thick. Although exhibiting in the intrados an elliptical curve, the arches are all perfect segments of circles of 60 degrees, with the voussoirs of the courses radiating to one centre; they are built with bricks 12 × 6 × 2½ inches. On some of the smaller bridges, rubble boulder masonry, and block kunkur have been used, the arches being of brick. The mortar used consisted of 1 part stone lime to 2 parts soorkhee, or 1 part stone lime, 1 part soorkhee, and 1 part sand.

The foundations varied from 4 to 10 in depth, where the ground was hard and of a tenacious quality. When the foundations were laid in sand, extra depth was given and wells were used, where necessary. All these bridges have floorings with curtains

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11'
26'
26'
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25'

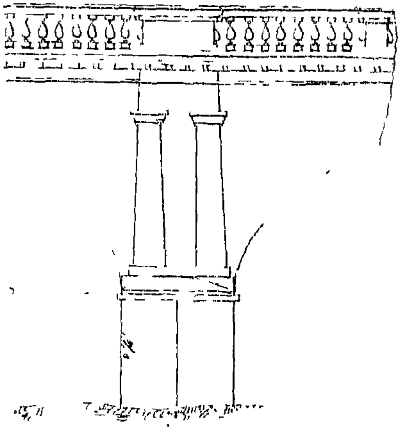
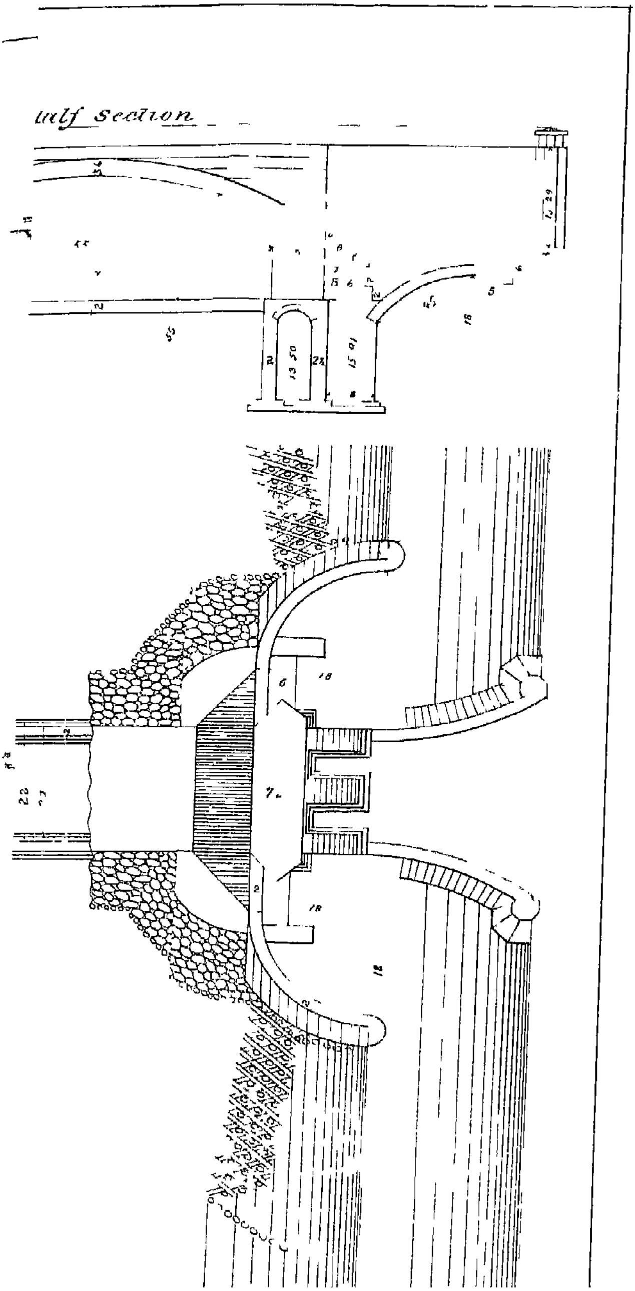


PLATE XXIII.



on the waterways (as deep as the river foundations), partly to give additional security to the bridge and partly to act as bars for retaining the canal levels.

Besides which, where the canal bed is sandy or of a light soil, the floorings are further protected by a mass of boulders in crib-work, 10 feet wide, and protected on the up and down-stream side by a line of sheet piling (*see* section).

The roadways are horizontal, and of a width varying from 18 to 25 feet in the clear according to their importance.

The centerings used are shown in Vol. I., page 289. The thickness of the arch is 3 feet. The bricks are laid in common bond with very fine joints, concentric rings not being used. The centerings were always gradually lowered within a few hours after the keying of the arch. The mean ultimate settlement was about 3 inches. The average cost of a bridge without ghâts, was Rs. 23,121, or Rs. 110 per lineal foot of waterway Average rate for masonry, being Rs. 14-7 per 100 cubic feet.

Bridge across the Tum Brapoorney, Tinnevelly.—This bridge was designed by Captain Faber, and built by Lieut. Horsley, Madras Engineers, in 1843; it consists of eleven elliptical arches of 60 feet span and 17 feet versed sine, standing on ten piers averaging 10 feet in height and the same in thickness, and two abutments measuring 15 feet in thickness at the springing courses.

The breadth over the soffit of the arches is 27 feet, of which 24 feet are occupied by the roadway, and 1½ feet on each side by the parapets. The total length between the abutments is 760 feet, or from the extremities of the wings 930 feet. The style of architecture is similar to that of Waterloo bridge over the Thames at London. The upper and lower faces of the bridge are ornamented with rows of coupled Doric columns standing on the ends of the piers and supporting an entablature and balcony above. The parapets are of open balustrade work finely polished with shell chunam, presenting an appearance of white marble, and giving to the whole structure an imposing effect.

The foundations of all but three piers, rest on hard kunkur rock at the depth of 8 or 10 feet. These three being situated in the sandy part of the river's bed, with a constant depth of 3 or 4 feet of water, were built on 3 rows of wells of 4 feet inner, and 6 feet outer diameter, to the depth of 10 feet, where a firm clayey bottom was met with. The wells were then filled in with cubes of masonry (made to fit the inner diameter) and the spaces between, with rubble stone in cement to the surface of the water. On these, as a foundation, were laid three courses of rough stones from the Palamcotta Fort walls, faced with cut stone, and bound together with iron cramps, set in lead. Above these, again, came brick in chunam to the required height. Lines of wells were also sunk in front and rear between Nos. 6 and 9 piers, to act as retaining walls to the pavement or flooring, which it was thought advisable to lay down for the protection of the foundations.

The centering adopted is shown in Vol. I., Plate XXIVA, and consisted of four parallel frames of anjelly timber (procured from Cochin) supported on twenty piers of brick-work built up to within one foot of the spring of the arch, with a wedge of the form shown in the plate on the top of each pier. The frames were connected transversely by struts and braces, and on top by palmyra pieces supporting the stuffing or mould, formed of bricks and clay (1 foot in thickness all round, and agreeing exactly with the curve of the intrados.)

The arch bricks made use of in this work were of different forms and sizes, to suit the radii of the curve, and laid according to the English bond, headers and stretchers alternately. Extra sized bricks were also used to break the joints.

The mortar was composed of 1 part of slaked lime to 1¾ parts of clean river sand, mixed with a little jagherry.

CHAPTER XXXII.

WOODEN BRIDGES.*

104. WOODEN Bridges are common in all parts of India where timber abounds, and where cheapness and expedition are important; wood has its objections in being less durable than either brick or stone, but if covered in and protected from the weather, it may be made to last a considerable time.

A timber bridge consists of three essential parts; 1stly, The frame or truss which supports the superstructure between the piers and abutments; 2ndly, The superstructure, consisting of the roadway, parapets, &c., &c.; and, 3rdly, The abutments and piers, which form the points of support for the bridge-truss.

The first of these, viz., the truss which supports the roadway, is by far the most important part of any bridge, and that which admits of the greatest variation in form and principle, and it is to this, therefore, that attention will be chiefly directed in this Chapter.

A bridge-truss is usually one of two or more parallel frames of carpentry, which act as girders in supporting the cross-beams or joists of the roadway platform. The most elementary figures of bridge trusses are like those of roof trusses, the triangle and the trapezoid, and the principles of their stability and equilibrium are the same; except that in a bridge-truss, *special provision must be made for the unequal distribution of the load, both transversely and longitudinally.*

The most simple support for a roadway evidently consists of a series of longitudinal timbers laid between two abutments, or piers. And, as the examination of this case will lead by easy gradations to others that are more complicated; and as it involves many of the principles which apply to structures of a more important character, both in Wood and Iron, it will be useful to investigate the forces which act upon a single beam laid between two supports, and loaded with a weight, either uniformly distributed or concentrated at any given point.

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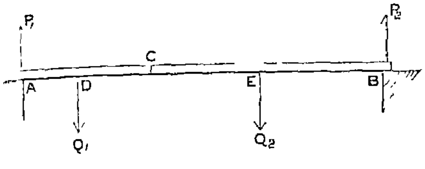
* I am indebted to Lieut. Conway Gordon, R.E., Assistant Principal, for nearly the whole of this Chapter

105. Let AB represent a beam loaded in any given manner and supported at A and B; and let P_1, P_2 represent the supporting forces, or re-actions of the abutments, which will depend both upon the amount of the gross load, and its mode of distribution.



Conceive a vertical section perpendicular to the longitudinal axis to devide the beam into two parts at any point C, and let Q_1, Q_2 be the resultants of the loads upon AC and CB.

Then, since the segment AC is acted upon by the two external forces P_1, Q_1; it follows that if the beam be strong enough to sustain the forces applied to it, there must be a vertical stress or *shearing force* distributed over the section at C, which is equal and opposite to the resultant of those two forces.

Therefore if S represents this shearing force

$$S = P_1 - Q_1 = P_2 - Q_2$$

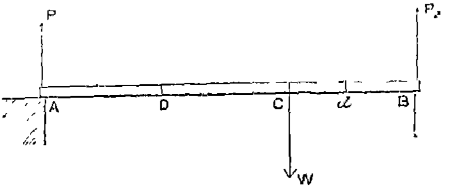
and acts in the direction of the lesser force, or vertically downwards. The effect of this shearing force is to crush across the fibres close to a fixed point, and the resistance which the material offers, is directly proportional to the area of the cross section.

It is evident too, that the two equal forces P_1 and $(Q_1 + S)$ applied in parallel and opposite directions, but not in the same line of action, constitute what is called *a couple*, whose tendency is to turn the segment AC round, or to bend the beam.

The moment of this couple, or the sum of the moments of the three forces P_1, Q_1, S about any point in the line AB, constitutes the *bending moment* of the beam at the vertical section in question.

The effect of this bending moment is to compress the fibres on the upper side, and extend them on the lower, the strain on any fibre varying directly as its distance from the neutral axis; or in other words, the bending moment arising from the load is resisted by the moment of the couple consisting of the thrust along the longitudinally compressed layers, and the equal and opposite tension along the longitudinally stretched layers

It therefore becomes of the highest importance to be able to ascertain the shearing force and bending moment at every point of a beam or girder, in order that every part may be properly proportioned to the stress it may be required to sustain.



106. *To find the shearing force and bending moment at any point arising from a single load.*—Let AB represent a beam supported at A and B; and, disregarding for the present its own weight, let it be loaded at the point C with a weight W. Take P_1, P_2 to represent the supporting forces AB, the span = l, AC = a.

Then $P_1 : P_2 : W :: CB : CA : AB :: l-a : a : l$

$$\therefore P_1 = W . \frac{l-a}{l} \text{ and } P_2 = W . \frac{a}{l} .$$

Then since from Art. 105, the shearing force at any given cross-section D, is the resultant of all the forces acting on the beam from either point of support to that cross-section, and the only force which acts upon AD is P_1, it follows that the shearing force S, at the point D, is P_1.

The same result could be obtained by taking the resultant of the forces which act upon the other segment DB, for then S would equal $W-P_2$ or P_1, the same as before.

As this is true for any point between A and C, and, as in a similar way it might be proved that the shearing force at any point between C and B is P_2, it is obtained that *in a beam, when the weight is not applied in the middle, the shearing forces on either side are constant, and equal to the pressures on the points of support.*

To find the bending moment at any point D, let AD = x; and bending moment = M.

Then taking moments about A; which is perhaps the most convenient place for doing so,

$$M = S \times x - P \times o = S x = P_1 x = \frac{Wx(l-a)}{l} .$$

In a similar way, for any point d on the other side of the weight W,

$$M = S \times d B = P_2 (l-x) = \frac{W . a (l-x)}{l} .$$

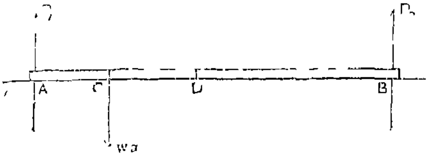
107. When the weight is applied at the centre,

$$P_1 = P_2 = \frac{W}{2}\text{; and consequently;}$$

the shearing force is constant at every point and equal to half the weight.

At any point x; for the half of the beam towards A, bending moment $M = \frac{W}{2} . x$, and in the other half, $M = \frac{W}{2} \; (l - x)$.

108. *To find the shearing force and bending moment at any point arising from a uniform load.*—Let the beam AB be uniformly loaded with a weight w on each unit of length, so that the gross weight $W = lw$, and as before $P_1 = P_2 = \frac{W}{2} = \frac{wl}{2}$.



Let D be any point in the beam at a distance x from A. Then, as the beam is uniformly loaded, the weight upon AD $= xw$ acting through its centre of gravity C, at a distance $\frac{x}{2}$ from A.

But since the shearing at D is the resultant of all the forces acting upon the segment AD,

$$\text{Shearing force } S = P_1 - wx = \frac{wl}{2} - wx = w\left(\frac{l}{2} - x\right)$$

Hence it follows that in a beam uniformly loaded, the shearing forces are exactly proportional to the distance from the centre, where the shearing force vanishes.

To find the bending moment, take moments about A; then as before

$$M = wx . \frac{x}{2} + S . x = \frac{wx^2}{2} + wx\left(\frac{l}{2} - x\right) = \frac{wx\,(l - x)}{2}.$$

Hence, in a beam uniformly loaded, the greatest bending moment acts at the centre, and $= \frac{wl^2}{8}$.

109. In a similar way, if the beam be divided into N divisions, each equal to $\frac{l}{N}$, and loaded with a weight w at each point of division; the points of division being numbered from both ends towards the middle.

$$\text{Since the total weight} = (N - 1)\,w$$

$$\text{and } P_1 = P_2 = \frac{N - 1}{2}\,w.$$

The shearing force immediately beyond

$$\text{1st division, from either end} = \frac{N - 1}{2}\,w - w = w\left\{\frac{N - 1}{2} - 1\right\}$$

2nd division, from either end $= \left\{\frac{N-1}{2} - 2\right\} w$

3rd " " $= \left\{\frac{N-1}{2} - 3\right\} w$

and generally,

nth " " $= \left\{\frac{N-1}{2} - n\right\} w$

Similarly, by taking moments about either point of support,—bending moment immediately beyond 1st division from either end

$$= \left\{\frac{N-1}{2} - 1\right\} w \,.\, \frac{l}{N} + w\,\frac{l}{N} = \frac{w\,l}{2N}\,(N-1)$$

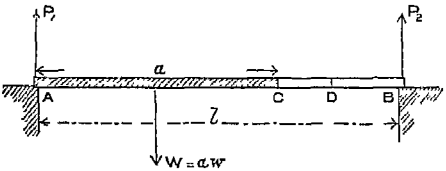
$$\text{2nd division} = \left\{\frac{N-1}{2} - 2\right\} w \,.\, \frac{l}{N} + \frac{w\,l}{N} + \frac{2\,wl}{N} = \frac{w\,l}{2N}\,.\,2\,(N-2)$$

$$\text{3rd division} = \left\{\frac{N-1}{2} - 3\right\} w\,\frac{l}{N} + \frac{w\,l}{N} + \frac{2\,wl}{N} + \frac{3\,wl}{N} = \frac{w\,l}{2N}\,.\,3\,(N-3),$$

and, generally, bending moment immediately beyond

$$n\text{th division, from either end} = \frac{w\,l}{2N}\,.\,n\,(N-n).$$

110. *To find the shearing force and bending moment arising from a partial load of uniform intensity.*—Let the beam AB be loaded for a length AC, $= a$, with a uniform load w on each unit of length, so that the gross load $W = aw$. Then since W acts at a distance $\frac{a}{2}$ from A



$$\text{therefore } P_1 = W\,.\,\frac{l - \frac{a}{2}}{l} = aw\left(1 - \frac{a}{2l}\right)$$

$$P_2 = W\,\frac{a}{2l} = aw\,.\,\frac{a}{2l}.$$

Hence it follows from the reasoning in Art. 106; that between C and B, the shearing force is constant and equal to $w\,.\,\frac{a^2}{2l}$; and from Art. 108, that the shearing force for any point between A and C, at a distance x from A, is

$$aw\left(1 - \frac{a}{2l}\right) - xw\,. = w\left(a - \frac{a^2}{2l} - x\right)$$

Consequently, since the shearing force at any point D in the unloaded segment $= \frac{w\,.\,a^2}{2l}$ or varies as a^2, *it will be the greatest when the longer of the two segments is wholly loaded, and the shorter unloaded,* a fact of the greatest importance in finding the greatest shearing force at any given section owing to a travelling load.

From Art. 106, it is evident, that at any point D in the unloaded segment,

$$M = S \times (l - x) = \frac{wa^2}{2l}(l - x).$$

And from Art. 108, that at any point in the loaded segment,

$$M = w\left(a - \frac{a^2}{2l} - x\right) \times x + w\,x \,.\, \frac{x}{2}.$$

$$= w\left\{a - \frac{a^2}{2l} + \frac{x^2}{2}\right\}$$

111. Similarly, if the beam be divided into N divisions, each equal to $\frac{l}{N}$; the points of division being numbered from both ends towards the middle; if the beam be supposed to be divided *immediately before* the nth joint, and each of the divisions in the longer segment, including the nth division, be loaded with a weight w, the others being unloaded—the shearing force at point of division

$$= \frac{N - n + 1}{2N}(N - n)\,w.$$

2ndly.—If the beam be supposed to be divided *immediately beyond* the nth joint, and all the divisions in the shorter segment, including the nth division, be loaded—the shearing force at point of division

$$= \frac{n \,.\, \overline{n + 1}}{2N} \,.\, w.$$

112. *To find the effect of combining several loads on one beam, whose separate actions are known.*—For each cross section, the shearing force is the sum of the shearing forces; and the bending moment, the sum of the bending moments, which the loads would produce separately.

113. *Travelling load.*—A beam of the span l is supported at the two ends; a permanent load of a uniform intensity, w lbs. per lineal foot, is distributed over it. An additional load, such as the weight of a railway train, of w' lbs. per lineal foot, gradually rolls on to the beam from one end, covering it at last from end to end, and then rolls off again at the other end—it is required to find the greatest shearing force and bending moment at any given section.

From Art. 110, the greatest shearing force at a given cross-section occurs, when the longer of the two segments into which it divides the beam, is loaded with the travelling load as well as with the permanent load, and the shorter is loaded with the permanent load only. Let S′ denote that force, and x the distance of the section in question from the nearer point of the beam; then from Arts. 108 and 110,

$$S' = w\left(\frac{l}{2} - x\right) + \frac{w'(l-x)^2}{2l}.$$

The greatest bending moment at each section occurs when the travelling load extends over the whole of the beam, so that in this respect no difference exists between the present case, and Art. 108, that is to say,

$$M = \frac{(w + w')\,x.\,(l - x)}{2}.$$

For timber bridges *not* carrying railways, the values of w and w' are nearly as follows:—

When there is a simple wooden platform $w = 30$ lbs. per square foot.

,, a broken stone roadway $w = 130$,,

Now, the greatest stress a roadway bridge has to sustain is due either to a dense crowd, or to the rapid passage of some heavy object, such as a loaded elephant. In the former case, a weight $w' = 120$ lbs. per square foot, may be supposed to be *gradually and uniformly* distributed over the bridge; and in the latter, a *sudden* weight, w, applied at the centre, where its bending moment will be the greatest; and in this latter case, the coefficient of safety, as shown in the next article, must be increased.

The weight of a loaded elephant is assumed as 10,000 lbs., supported on two points, 5 feet apart.

114. *Swiftly rolling load.*—A suddenly applied transverse load produces double the strain which the application of a load, gradually increasing from nothing to the amount of the given load, would produce. The action of the rolling load to which a bridge is subjected is intermediate, in those cases which occur in practice, between that of an absolutely sudden load and a perfectly gradually load. *The additional strain arising from the swift motion of the load, must be provided for in practice, by making the factor of safety for the travelling part of the load, about half as much again as the factor of safety for the fixed part.*

115. *Allowance for weight of beam.*—When a beam is of great span, its own weight may bear a proportion to the load which it is to carry, sufficiently great to require to be taken into account in determining the dimensions of the beam. The following is the process to be performed for that purpose, when the load is uniformly distributed, and the beam of uniform cross section.

Let W' be the external working load, s' its factor of safety, s a factor of safety suited to a steady load like the weight of the beam.

Let b' denote the breadth of any part of the beam, as computed by considering the external breaking load alone, $s'\,W'$. Compute the weight of the beam from that provisional breadth and let it be denoted by W. Then $\frac{s'W'}{s'W' - sW}$ is the proportion in which the gross breaking load exceeds the external part of the load. Consequently, if for the provisonal breadth b', there be substituted the exact breadth $b = \frac{b'\,s'\,W'}{s'W' - sW}$ the beam will be strong enough to bear the proposed load W' and its own weight.

116. As the best authorities differ somewhat in the rules they give for fixing the scantling of the main pieces of timber that compose a structure of carpentry, it is as well to remark that in all cases the following formulæ have been used in calculating the scantlings of rectangular beams.

For transverse strain .... $bd^2 = \frac{6.M}{f}$ .... (1)

For ties and struts whose length does not exceed *twenty times their thickness*, $\Big\}$ $bd = \frac{H}{f}$ .... (2)

For struts, whose length is over twenty times their thickness,.................... $\Big\}$ $bd = \frac{H}{300,000}\cdot\frac{l^2}{b^2}$ .... (3)

For ties and struts acted upon by a transverse stress in addition to that along their lines of resistance, ... $\Big\}$ $b = \left\{\frac{H}{d} + \frac{6.M}{d^2}\right\} \div f$ (4)

Where $M =$ the greatest working bending moment *in inch pounds.*

$H =$ the greatest working direct stress, whether tension or thrust *in pounds.*

l, b, d, represent the scantling of the beam in question *in inches;* and f, the greatest safe working intensity of stress, whether compressive or tensile *for a permanent load, which it is usual to limit to* 1000 lbs. *per square inch of section,* (*vide* Chapters VII. and VIII. of Vol. I.).

117. *To calculate the scantling of a beam, forming one out of several girders laid from abutment to abutment, and supporting the roadway platform.*—Let S be the span, and B the breadth of the bridge in inches, and n the number of girders of breadth b, and depth d inches; and let the permanent load be represented by w, and the greatest travelling load either by w' lbs per square foot, uniformly distributed, or by W lbs. applied suddenly at the centre.

The weight per unit of length due to $w = \frac{B\,.\,w}{n\,.\,144}$.

" " to $w' = \frac{B\;w'}{n\,.\,144}$.

∴ from Art. 108, greatest bending moment due to w and w'

$$\text{is } \frac{B\,(w+w')}{n\,.\,144}\,.\,\frac{S^2}{8}$$

and from Arts. 107 and 108, greatest bending moment due to w and W

$$\text{is } \frac{B\,w}{n\,.\,144}\,.\,\frac{S^2}{8}+\frac{W}{2}\,.\,\frac{S}{2}$$

Hence, from equation (1) Art. 116;

$$bd^2=\frac{6\;B\,(w+w')}{n\;.\;144}\,.\,\frac{S^2}{8}\times\frac{1}{1000};\text{ or }=\left\{\frac{B\,w}{n\,.\,144}\,.\,\frac{S^2}{8}+\frac{3}{2}\,.\,\frac{W}{2}\,.\,\frac{S}{2}\right\}\frac{1}{1000}$$

the bending moment for the suddenly applied weight being increased by one-half, according to Art. 114.

From this, the value of bd^2 can be found, so that by assuming the depth such as to avoid excess of deflection, the breadth is at once ascertained. The depth of a beam should not be less than about $\frac{1}{20}$ the span.

Example.—To find the scantlings of the girders for the bridge represented in Plate XXV., *Fig* 1, consisting of 13 beams, supporting a roadway of broken stone 18 feet wide, the span being 15 feet; upon the supposition of its having to sustain a dense crowd.

In this case S = 15 feet = 180 inches.
B = 18 " = 216 "
w = 130 lbs. per square foot (Art. 113).
w' = 120 " "
n = 13 " "

$$\therefore \text{Greatest bending moment} = \frac{216\,(130+120)}{13\times 144}\,.\,\frac{180^2}{8}$$

Hence from equation (1), Art. 116,

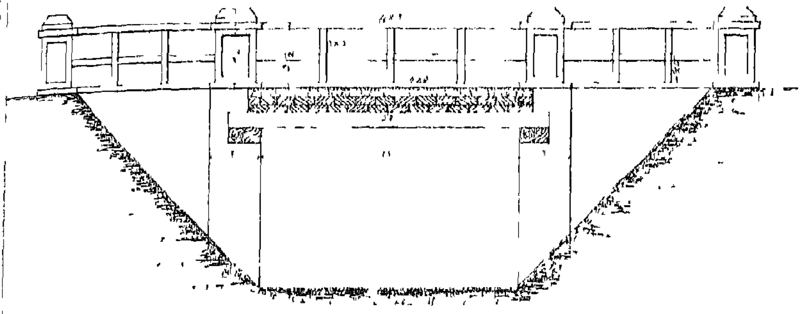
$$b'd^2=\frac{6\times 216\times 250\times 180^2}{13\times 144\times 8\times 1000}=701\text{, nearly};$$

and assuming the depth as 10 inches, the provisional breadth of the beam will be 7 inches.

Assuming the weight of the beam as about 400 lbs. the external load being 5200 lbs. nearly, from Art. 115,

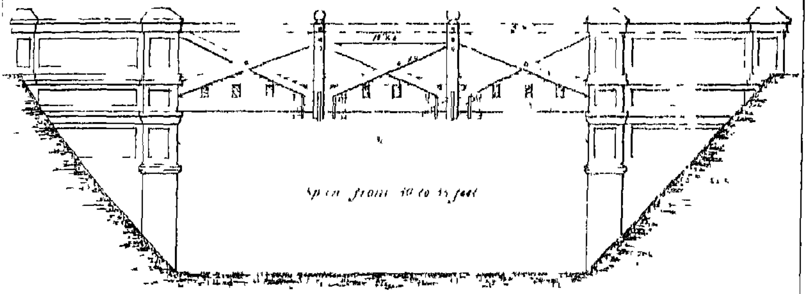
WOODEN BRIDGES.

Fig 1

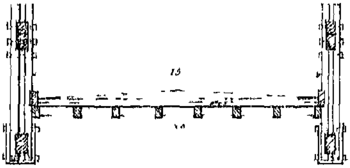


N.B. Central interval between Girders 15 feet

Fig 2



Cross Section through
Queen Post



$$\text{Proper breadth} = 7 \cdot \frac{5200}{5200 - 400} = \frac{7 \times 13}{12} = 7\tfrac{1}{2} \text{ inches, nearly.}$$

Hence the proper scantling is 10 by $7\frac{1}{2}$.

Example 2.—To find the scantling of the same beam, upon the supposition of the bridge having to support two loaded elephants a-breast, each weighing 10,000 lbs.

Great bending moment due to $w = \frac{216 \times 130 \times 180^2}{13 \times 144 \times 8}$; and from Art 106, considering that the supports of the two elephants will be 5 feet, from either extremity; the greatest bending moment at the centre due to $W = \frac{20000 \times 5 \times 90}{15 \times 13}$.

$$\text{Hence } bd^2 = \frac{6}{1000} \left\{ \frac{216 \times 130 \times 180^2}{13 \times 144} + \frac{3}{2} \cdot \frac{20000 \times 5 \times 90}{15 \times 13} \right\}$$

$$= 6 \left\{ 60{\cdot}75 + 69{\cdot}23 \right\} = 780, \text{ nearly.}$$

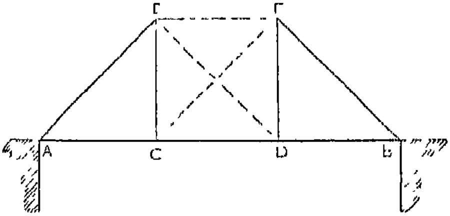
And assuming, as before, the depth of the beam as 10 inches, the provisional breadth will be 8 inches, nearly.

And since the gross load $= \frac{18 \times 15 \times 130}{13} + \frac{20000}{13} = 2700 + 1500$, nearly; if the weight of the beam be taken as before, the proper breadth $= 8 \cdot \frac{2700 + \frac{3}{2} \cdot 1500}{2700 + \frac{3}{2} 1500 - 400}$ $= 8 \cdot \frac{4950}{4550} = 9$ nearly; or the proper scantling is 10 by 9.

118. *Trapezoidal truss.*—When the span becomes considerable, simple timbers are insufficient, and framed trusses become necessary. Whatever may be their particular form, the object in every case is obviously to dispose of a given quantity of material, so as to resist effectually all the forces which tend to produce rupture.

The commonest example in practice is that of the trapezoidal truss, either springing from a tie-beam as in *Fig.* 1, or from a pair of abutments as in *Fig.* 2, which figure is well suited for spans of 30 or 40 feet in this country, as it can be made up with short timbers.

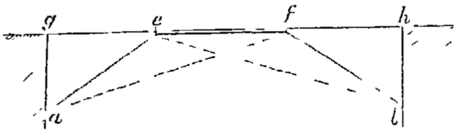
Fig. 1.



This truss consists essentially of two struts, AE, FB, or *ae*, *fb*, kept apart by the straining beam EF or *ef*; the roadway being either suspended by means of the ties EC, FD, in *Fig.* 1, or else resting immediately above the truss as

To find the stresses upon the different bars of the trapezoidal truss, AEFB. — Let AC = DB = l; CD = l', and breadth of bridge = B, *all in inches*, the number of trusses = n, w the permanent load, and w' the greatest travelling load per square foot; and the inclination of the struts to the horizon = α. The point F may be assumed to sustain one half the load upon CD, and one half that upon DB,

Fig. 2.



∴ the load sustained at F, or the stress upon tie FD,

$$= W = \frac{(l + l')}{2} \cdot \frac{(w + w')\,B}{144 \,.\, n}.$$

And since the sides of the triangle FDB are respectively parallel to the lines of action of the stresses along EF, FB, and FD, therefore

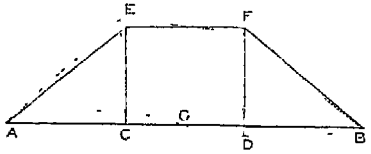
W : stress along EF : stress along FB : : FD : DB : FB

$$\therefore \text{ stress along EF} = \text{stress along AB} = W.\frac{DB}{FD} = \frac{l + l'}{2} \cdot \frac{(w + w')B}{144 \,.\, n} \cdot \cot \alpha$$

$$FB = \frac{W.\,FB}{FD} = \frac{l + l'}{2} \cdot \frac{(w + w')\,B}{144 \,.\, n} \cdot \operatorname{cosec} \alpha$$

But the tie-beam AB having to support the roadway joists, will be subject to a bending moment in addition to the stress in the direction of its length, and from Art. 108 this greatest bending moment $M = \frac{B\,(w + w')}{n \,.\, 144} \cdot \frac{l^2}{8}$, or $\frac{B\,(w + w')}{n \,.\, 144} \cdot \frac{l'^2}{8}$; according as l or l' is the greater. Next, suppose a partial load W′ be concentrated at one of the points C or D; the point D for instance, the other point C being unloaded. Then, if the truss is strong enough to support the load, it is evident that $\frac{W'l}{2l + l'}$ is supported at A, and $\frac{W'\,(l + l')}{2\,l + l}$ at B.

Fig. 3.



Hence the stress on

AE resolved vertically, or the force acting upward on the point C $= \frac{W'l}{2l + l'}$

FB ” ” ” ” D $= \frac{W'(l + l')}{2l + l'}$.

But this latter point D, is also acted upon by the weight W downwards.

$$\therefore \ W' - \frac{W'(l + l')}{2l + l'} = \frac{W'l}{2l + l'}$$

is the resultant acting downwards on the point D.

From this it appears that the action of a partial load is to tend to raise the point C, and depress the point D, or to distort the truss into the position shown by the dotted lines.

Hence the beam may be considered *fixed at the points* A, G, B, *the segment* AG being acted upon by a force $\frac{W'l}{2l + l'}$ acting upwards at C, and the segment GB by an equal force acting downwards at D, the value of the bending moment in both cases being $\frac{W'l}{2l + l'} + \frac{l'}{2}$.

There are two ways of enabling the truss to resist this action; either by diagonal bracing, or by the stiffness of the longitudinal beam running from one end of the truss to the other, which beam is either the tie-beam as in *Fig.* 1, or that resting immediately above the truss and bolted to the straining piece as in *Fig.* 2.

If the stiffness of the longitudinal beam be trusted to; the bending moment $\frac{W'l}{2l + l'} \times \frac{l'}{2}$ must be taken into account in fixing its dimensions.

As in India, however, pieces of wood of long scantling are difficult to procure, and the tie-beam is usually made up of two or more pieces scarfed together, or by an iron tie-rod, no dependence can be placed upon the stiffness of the longitudinal beam. The truss is usually therefore diagonally braced, as shown by the dotted lines in *Fig.* 1; the brace FC acting when the partial load is at F, and ED when the load is at C.

To calculate the stress upon the braces.—Since the vertical force they have to sustain is $\frac{W'l}{2l + l'}$; if they be inclined at an angle β to the horizon, the stress along them $= \frac{W'l}{2l + l'} \cdot \operatorname{cosec} \beta$.

In *Fig.* 2, where the struts spring immediately from the abutments, and the roadway is supported above the truss; the stresses upon the struts, *ae*, *fb*, straining piece *ef*, and braces *af*, *eb*, are exactly the same as before. The horizontal thrust of the foot of the struts upon the abutment is the same as the stress of the tie-beam, viz., $\frac{l + l'}{2} \cdot \frac{(w + w')\,B}{n \,.\, 144} \cdot \cot \alpha$, and the longitudinal beam must be strong enough to sustain the greatest bending moment due to the weight upon *ge* or *fh*, or

$$\frac{(w+w')\,B}{144\,.\,n}\,.\,\frac{l^2}{8}$$

If $l = l'$; or the span is divided into three equal parts, these formulæ become

Stress on strain-piece = stress on tie-beam = horizonal thrust on

Abutment, $= \dfrac{(w+w')\,Bl}{n.144}\,.\,\cot\alpha.$

Stress on struts, $= \dfrac{(w+w')\,Bl}{n.144}\,.\,\operatorname{cosec}\alpha.$

Stress on ties, EC and FD $= \dfrac{(w+w')\,Bl}{n.144}.$

Stress on braces, $= \dfrac{W'}{3}\,.\,\operatorname{cosec}\beta.$

Bending moment on longitudinal beam $= \dfrac{B\,(w+w')}{n\,.\,144}\,.\,\dfrac{l^2}{8}.$

Example.—To calculate the scantlings of the timber of the bridge given in Plate XXV., *Fig.* 2, consisting of two trapezodial trusses of 30 feet span, supporting a metalled roadway 15 feet broad, upon the supposition of its having to sustain a dense crowd.

The superstructure of this bridge consists of two trusses, each formed of a straining beam, *aa*, a tie-beam, *bb*, two struts, *cc*, and two queen-posts, *dd*. The queen-posts are double and are indented to a depth of one inch at their intersection with the tie-beam and the straining piece, to which they are attached by means of iron straps and bolts. The tie-beam is formed of three pieces scarfed together, the scarfs being placed at the intersections of the tie-beam with the queen-posts. The ends of the struts are joined to the tie-beam in the manner shown in figure, and are further secured in their places by bolts and straps. The roadway girders are placed 2 feet apart from each other, and are covered with 3-inch planking and a layer of earth to form the road-surface. The trusses are stiffened by cross-braces, *ee*, which, together with the struts, and the cap piece, *ff*, which runs parallel to the tie-beam, form a handsome railing to the bridge.

In this case $l = l' = 120$ inches, $B = 180$
$w = 130$, $w' = 120$ lbs. per square foot.
$n = 2$, and $\alpha = 20°$.

$$\text{Stress upon the ties} = W = \frac{(120 + 130)\,.\,120\,.\,180}{2 \times 144} = 18750$$

Stress upon the struts $= W \operatorname{cosec}\alpha = 18750\,.\,\operatorname{cosec} 20° = 54750$ lbs.
Stress upon straining beam and tie-beam $= 18750 \cot 20° = 51513$ lbs.

$$\text{Greatest bending moment on the beam} = \frac{180\,.\,250\,.\,120^2}{2\,.\,144\,.\,8} = 281250 \text{ inch lbs.}$$

$\therefore$ from equation (2) Art. 116.

$$\text{Section of ties} = \frac{18750}{1000} = 19 \text{ square inches, nearly.}$$

$$\text{,,} \qquad \text{struts} = \frac{54750}{1000} = 55 \qquad \text{,,} \qquad \text{,,}$$

$$\text{,,} \qquad \text{straining beam} = \frac{51513}{1000} = 52 \text{ square inches, nearly.}$$

∴ Scantling of ties may be taken as 5 × 4.
,, struts ,, 8 × 7.
,, straining ,, 8 × 7.

To fix the scantling of the tie-beam, from equation (4), Art. 116,

$$b = \left\{ \frac{H}{d} + \frac{6\,M}{d^2} \right\} \frac{1}{1000} = \frac{57{\cdot}513}{d} + \frac{281{\cdot}250 \times 6}{d^2}$$

and assuming the depth as 14 inches,

$$b = \frac{51{\cdot}513}{14} + \frac{1687{\cdot}5}{196} = 3{\cdot}6 + 8{\cdot}5 = 12, \text{ nearly.}$$

To calculate the stress upon the braces, suppose a loaded elephant to be supported immediately above one of the points of division.

$$\text{Then the stress on the brace} = \frac{10000}{3} \,.\, \text{cosec } 20^\circ = 9746 \text{ pounds.}$$

$$\therefore \text{Section required} = \frac{9746 \times 3}{2} \times \frac{1}{1000} = 15 \text{ square inches, nearly ; or the brace}$$

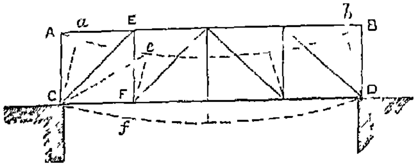
might be made 5 × 3.

119. *Girder Bridges.*—Since the fibres of a beam near the neutral axis are but little strained, and consequently oppose but little resistance, they could be removed without serious injury, and if the same amount of material could be disposed at a greater distance from the axis, the strength would be increased in exact proportion to the distance at which the fibres could be made to act. Hence, the first object in designing a girder is to place the material to resist the bending moment, at the greatest distance from the neutral axis which the nature of the structure will admit.

It is evident, however, that if two longitudinal timbers were placed parallel to each other, without intermediate connections, nothing would be gained; each would act independently of the other, and the strength would be less than that of a single beam. Neither would a connection by means of vertical-ties, as in *Fig.* 4, add to the strength, for the weight of the ties would merely increase the load, to resist which there would be only the stiffness and strength of the two beams AB and CD.

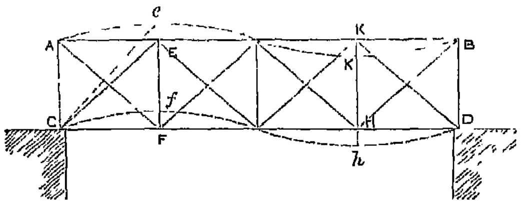
But, by observing the effect of flexure upon this system, the means by which any alteration of form can be prevented, is seen at once.

Fig. 4



1*st.*—Suppose the system under the action of a *uniform load.* Then it is evident that the rectangles formed by the horizontal and vertical pieces are converted into oblique-angled parallelograms, one diagonal, such as CE being shortened into *ce*, and the other, AF, being lengthened. And as this effect must take place to a greater or less extent whenever any degree of flexure is produced, it may be concluded that the introduction of struts, such as CE, to prevent any change of figure in the rectangles will effectually prevent flexure. It appears, therefore, that in the construction of a bridge-girder, three series of timbers, *at least*, enter as indispensable elements: these may be called chords, ties and braces; and these are all that a *uniform* load requires.

2*ndly.*—Let the weight, instead of being uniformly distributed, be applied at some point H.



Then, since by precisely the same reasoning as in Art 118, the weight upon one side will cause a tendency to rise upon the other, the flexure of the system will be somewhat as shown by the dotted lines. The effect of this upward force is to extend some diagonals in the direction of the braces; but as the braces, from the manner in which they are usually connected with the frame are not capable of opposing any force of extension, it follows that the only resistance is that due to the weight of a part of the structure. The remedy for this is obvious: it is only necessary to prevent the diagonals, such as AF from shortening, or in the direction of the brace, from lengthening, and the upward force will be effectually resisted. This requires, either, that counterbraces, such as AF, should be introduced throughout the stress, or that the braces, should be capable of acting as ties. It follows, therefore, that no bridge, either arched or straight, which is designed for the passage of travelling loads, should be constructed without counterbracing, or diagonal ties. It is only in aqueducts, where the load is always uniform, that they can be omitted.

120. *To compute the stresses along the bars of a Bridge Girder.*—The most convenient way of determining the stresses along the different bars of a girder is by the *method of sections.*—The theorem, upon which this depends, will be found demonstrated generally in "Rankine's Applied Mechanics;" but it is sufficient for the present purpose to state it particularly as follows:—

That if an ideal vertical section be made through the bars of a girder acted upon by vertical forces *alone.*

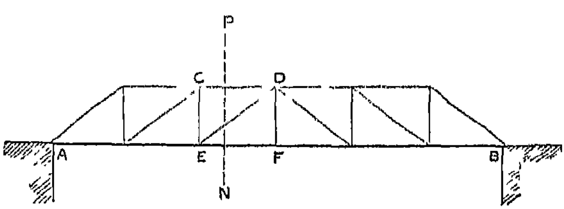
1st. The sum of the horizontal components of the stresses along the bars cut by the plane of section in one direction, balance the sum of those in the other direction, ... (1)

2nd. The sum of the vertical components of the same stresses balances the shearing force at the plane of section, ... (2)

3rd. The moment of the couple formed by the equal and opposite stresses of equation (1) balance the bending moment at the plane of section, ... (3)

From these three equations, the stresses along the bars may be determined, provided but *three* bars are cut by the plane of section; if more than three bars are cut the problem is or may be indeterminate.

For instance, to determine the stresses on the bars CD, DE, EF of the girder AB; suppose a vertical section to be made on the line PN; let H be the stress along EF; H_1, that along CD, and T that along ED, the angle DEF $= \alpha$, and the heighth CE of the girder $= k$.



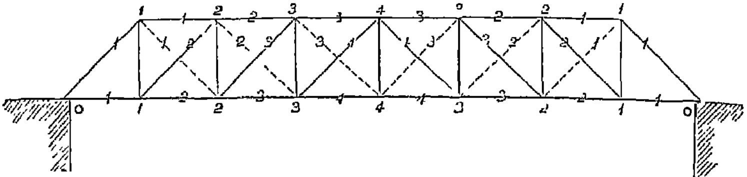
Then $H_1 + T \cos \alpha = H$, ... (1)

$T \sin \alpha =$ shearing force at plane of section PN, ... (2)

$Hk =$ bending moment at plane of section,................ (3)

and from these three equation, H, H_1, and T can be found; the shearing force and bending moment being determined by Arts. 106 and 113. It is, therefore, only necessary to apply these equations to each division of the girder successively; remembering that to find the *greatest* stress along any particular bar, there must be substituted in equations (2) and (3) the *greatest* shearing force or bending moment which can possibly arise from the different arrangements of the rolling load combined with the permanent load.

121. *Diagonally Braced Girder.*—This sort of girder, of which the figure is a skeleton drawing, was first introduced in America by Mr. Howe. The two horizontal chords resist the bending action of the load, they are made of layers of planks set on edge, and bolted together to break joint. The shearing action of the load is resisted by the vertical suspending ties, (which are iron rods,) and the braces and counterbraces.



The braces shown by full lines, are, as before remarked in Art. 119, all that would be required, if the load were always uniformly distributed over the girder. The counterbraces shown by dots are necessary to resist travelling loads.

To compute the stresses upon the different bars of a Howe's Girder.—The points of support being numbered 0, the joints and divisions of the horizontal booms are to be numbered 1, 2, 3, &c., from both ends towards the middle; the ties, braces, and counterbraces being designated by the number of the joint where their *upper* ends meet.

Let N, be the total number of divisions in the beam (in the figure $N = 8$).

l, the span, so that $\frac{l}{N}$ is the length of one division.

s, the length of a diagonal measured along its line of resistance.

k, the height of the girder measured from centre to centre of the horizontal chords.

w, the uniform steady load upon each joint.

w', the greatest travelling load upon each joint.

Also let H_n, be the thrust or tension along the nth division of the chords.

V_n, the tension along the nth tie,

T_n, the thrust along the nth brace,

t_n, the thrust along the counterbraces,

and the platform be supposed hung from the girder.

To find the stress upon the horizontal chords.—By Articles 108 and 112, the greatest bending moment at any point is when the travelling load extends over the whole of the beam; and immediately beyond the nth division $= \frac{w + w'}{2\,N} \,.\, ln\,(N - n)$.

$$\therefore \text{ by equation (3), Art. 114,}$$

$$H_n \,.\, h = \frac{w + w'}{2\,N} \,.\, ln\,(N - n).$$

$$\therefore\ H_n = \frac{w + w'}{h} \,.\, l\,n \,.\, \frac{N - n}{2\,N} \ \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

To find the strain upon the braces.—The brace n has to sustain the shearing force along the nth division, or that immediately beyond the $(n - 1)$th joint. Now, by Art. 108, the shearing force due to permanent load w, immediately beyond the $(n - 1)$th joint $= \left\{\frac{N + 1}{2} - n\right\} w$. And by Art. 109, the greatest shearing force due to the travelling load, is when the larger segment is loaded and the shorter unloaded, and is equal

$$\text{to } \frac{N - n + 1}{2\,N}\,(N - n)\,w'$$

$$\therefore \text{ total shearing force} = \left\{\frac{N + 1}{2} - n\right\} w + \frac{N - n + 1}{2\,N}\,(N - n)\,w'.$$

Hence by equation (2) Art. 120,

$$T_n\,\frac{h}{s} = \left\{\frac{N + 1}{2} - n\right\} w + \frac{N - n + 1}{2\,N}\,(N - n)\,w'$$

$$\therefore\ T_n = \left\{\frac{N + 1}{2} - n\right\} \frac{w\,s}{h} + \frac{N - n + 1}{2\,N}\,(N - n)\,\frac{w'\,s}{h}\ \ldots..\ (2)$$

To find the tension on the ties.—Every tie n, except the middle one, has to bear the same shearing force as the brace n.

$$\therefore\ V_n = \left\{\frac{N + 1}{2} - n\right\} w + \frac{N - n + 1}{2\,N}\,(N - n)\,w'\ \ldots\ldots\ (3)$$

$$\text{For the middle tie, } n = \frac{N}{2}$$

$\therefore$ The greatest shearing force due to the travelling load

$$= \frac{N - \frac{N}{2} + 1}{2\,N} \,.\, \left(N - \frac{N}{2}\right) w = \frac{w'}{4}\left\{\frac{N}{2} + 1\right\}$$

$$\therefore \text{ tension of the middle tie} = w + \frac{w'}{4} \,.\, \left\{\frac{N}{2} + 1\right\}\ \ldots\ldots\ (4)$$

When N is odd, there is no middle joint.

When the platform rests upon the top of the girder, subtract $(w + w')$ from each of the values of (3) and (4).

To find the stress upon the counter braces.—By the same reasoning, as in Art. 120, the smaller segment covered with the travelling load will cause a tendency to rise through the longer segment; the value of this shearing force immediately beyond the nth joint is $\frac{n(n+1)}{2N} w'$ upwards (Art. 110), and the uniform load will cause a shearing force at the same point $\left\{\frac{N-1}{2} - n\right\} w$ downwards; the counter brace has to resist the difference of these two forces.

$$= \frac{n(n+1)}{2N} . w' - \left\{\frac{N-1}{2} - n\right\} w.$$

$$t_n = \frac{n(n+1)}{2N} . w' - \left\{\frac{N-1}{2} - n\right\} \qquad \text{............} \ (5)$$

And when this gives a null or negative result, it shows that the platform has no tendency to rise, or that the counter brace is unnecessary.

The best angle of inclination for the braces and counter braces is 45°.

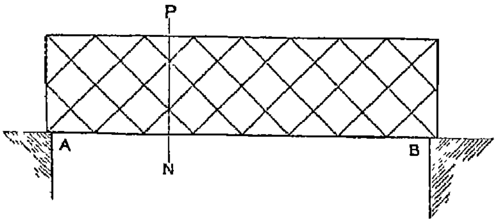
Example.—Required the stresses on the chords, &c., of a Howe's girder; the span being 80 feet, divided into 8 equal divisions, the height of the girder 10 feet, and the platform hung; upon the supposition of its having to support a uniform load of 5,000 lbs. and a travelling load of 10,000 lbs. per each joint:—

that is $l = 80$, $N = 8$, $h = 10$, $s = 14{\cdot}14$, $w = 5{,}000$ lbs., $w' = 10{,}000$.

n.	H.	v.	T.	t.
1	52,500	52,500	74,235	negative.
2	90,000	38,750	54,792	negative.
3	112,500	26,250	37,128	7,070
4	120,000	17,210	21,210	...

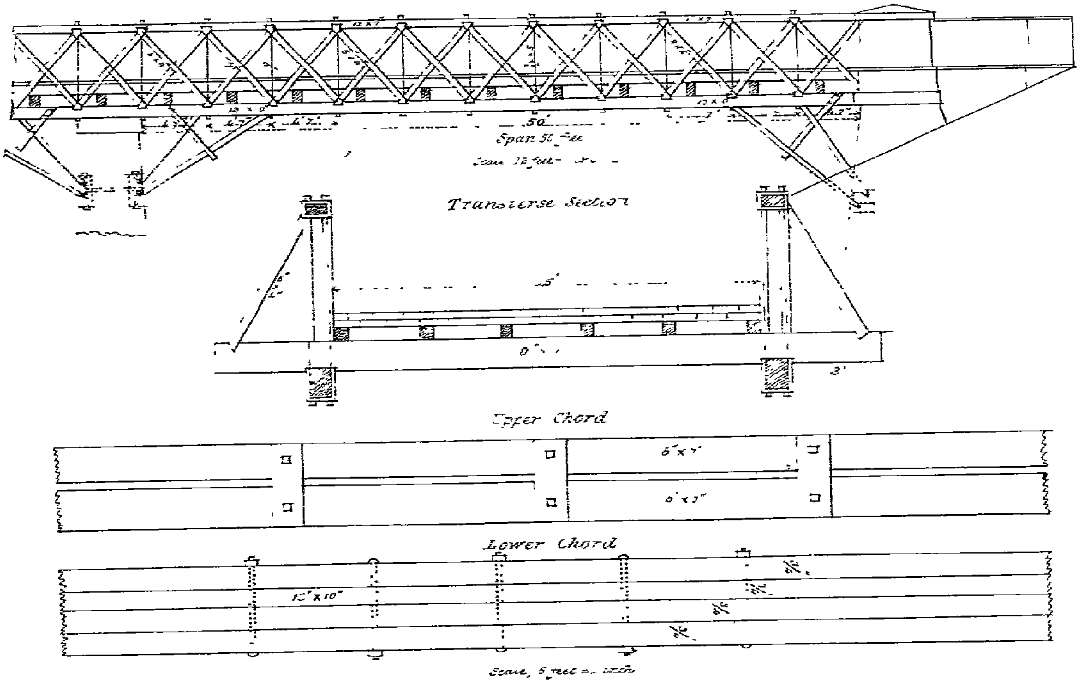
The value of H_4 applies to the lower chord alone, as the upper chord has only three divisions on either side.

122. *Lattice work girders.*—In the Lattice girder the top and bottom chords are connected by planks inclined at 45° to the horizon, crossing each at right angles and pinned together by treenails.



Suppose the girder to be cut by a vertical section PN. Then, since more than three bars are cut by the section, the problem of finding the exact stress upon each bar, is, in a strictly mathematical sense, indeterminate, as stated in Art. 120; but it is solved by

WOODEN BRIDGES.



Howe's Trellis Bridge.

Span 50 feet

Scale 12 feet = 1 inch

Transverse Section

Upper Chord

Lower Chord

Scale, 5 feet = 1 inch

taking for granted (what is the fact in well-constructed lattice girders,) that the shearing action of the load is distributed equally amongst the diagonal bars or planks.

And, since the horizontal components of the stresses along the diagonals balance each other, therefore by equation (1) Art. 120, the tension along the lower chord must equal the thrust along the upper.

Let H, be the tension along the lower and thrust along the upper chord.

R, the stress along each diagonal.

m, the number of the diagonals cut by the vertical section.

h, the height of the girder.

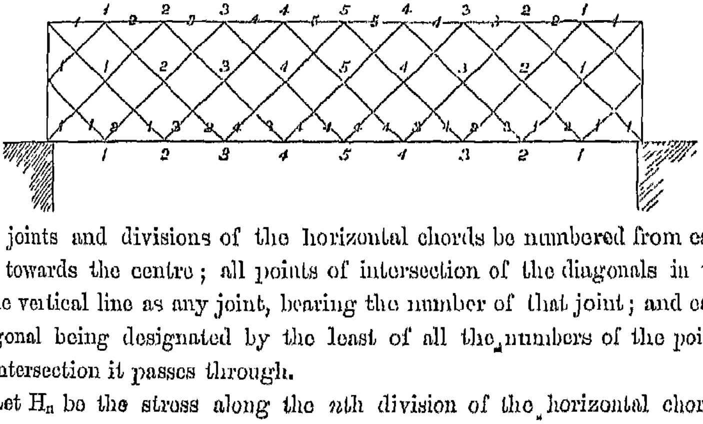
a, the inclination of the diagonals.

Then by equations (2) and (3), Art. 120,

$$m \,.\, \mathrm{R} \,.\, \sin a = \text{shearing force at given section,}$$
$$\mathrm{H}\, h = \text{bending moment.}$$

And from these equations, the value of R and H at any point can be determined; the shearing force and bending moment being calculated as before.

To compute the stresses upon the different bars of a lattice girder.—Let



the joints and divisions of the horizontal chords be numbered from each end towards the centre; all points of intersection of the diagonals in the same vertical line as any joint, bearing the number of that joint; and each diagonal being designated by the least of all the numbers of the points of intersection it passes through.

Let H_n be the stress along the nth division of the horizontal chords.

R_n ,, ,, diagonals.

w and w', the permanent and travelling loads upon each joint.

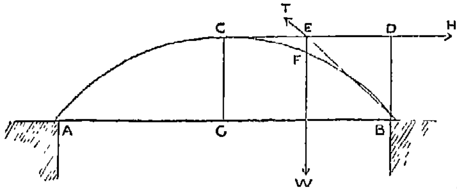
Then, in the same manner as before,

$$\mathrm{H}_n = \frac{w + w'}{h} \times l\, n\, \frac{\mathrm{N} - n}{2\,\mathrm{N}} \dots\dots\dots\dots\dots\dots \quad (1)$$

$$\text{and } \mathrm{R}_n = \left[\frac{w\,s}{h}\left\{\frac{\mathrm{N}+1}{2} - n\right\} + \frac{w'\,s}{h} \,.\, \frac{(\mathrm{N}-n)\,(\mathrm{N}-n+1)}{2\,\mathrm{N}}\right] \div m \quad (2)$$

123. *Timber Bow-string Girder.*—In a girder of this kind, a timber arch springs from a tie-beam, which supports the cross beams of the platform, and is hung from the arch at intervals by vertical ties, with diagonal braces between them.

To find the conditions of equilibrium of a timber arch under a uniform vertical load. By a uniform vertical load is here meant a vertical load uniformly distributed along a horizontal straight line, so that if C be the highest point of the rib, the weight suspended between C and F, shall be proportional to CE.



Let weight upon the half arch $= \frac{W}{2}$, thrust at C $=$ H, and thrust at B in direction of the tangent $=$ T. Then, since the half arch is kept at rest by these three forces, they must evidently meet in a point; but because the weight between B and G is uniformly distributed, its resultant must bisect CD, and therefore the tangent at B bisects CD, and this is the property of a parabola.

Hence the proper curve for a timber arch under a uniform load is a parabola with its vertex at C. Also, since the sides of the triangle BED are respectively parallel to the directions of these forces.

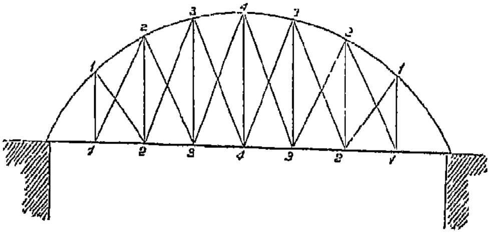
$$\therefore H : T : \frac{W}{2} :: ED : BE : BD$$

$$\therefore H = \frac{W.ED}{2.BD} \qquad T = \frac{W.BE}{2.BD}$$

and horizontal component of T

$$= \frac{W\ BE}{2.BD} \cos. BED = \frac{W.BE}{2.BD} \cdot \frac{ED}{BE} = \frac{W.ED}{2.BD} = H.$$

To compute the strains upon the different bars of a Timber Bow-string



Girder.—Let N be the total number of divisions in the tie-beam,

l, the span, so that $\frac{l}{N}$ is the length of one division,

k, the greatest depth of the truss,

w, the permanent load upon each joint,

w', the travelling load upon each joint,

so that the total load $= (N - 1)(w + w') = W$.

To find the stress at the crown of the rib and tension of the tie-beam.—

$$H = \frac{W}{2} \cdot \frac{l}{4} \div k = \frac{N-1}{8}(w - w')\frac{l}{k} \;\ldots\ldots\ldots\ldots\ldots (1)$$

Should the weight of the platform, instead of being concentrated at the joints, be partly supported by the tie-beam between the suspending pieces; the tie-beam will have to bear a tension $= H$, and a bending moment due to the load supported between the ties; and its scantling must be determined by equation (4), Art. 116.

To find the stress upon the ties.—The greatest tension of the tie-rod n is evidently the weight of the permanent and travelling load supported at that point added to the shearing force arising from a partial load w' over the shorter segment from 1 to $(n-1)$.

$$\text{This shearing force} = \frac{(n-1)\,n}{2\,N} \cdot w' \text{ (Art. 110).}$$

$$\therefore \text{ Total tension of tie } n = (w + w') + \frac{n-1}{2\,N} \cdot nw' \;\ldots\ldots\ldots (2)$$

To find the stress upon the diagonals.—The greatest stress upon the diagonals between n and $(n + 1)$ is the shearing force due to partial load w' over the shorter segment from 1 to n.

$$\text{This shearing force} = \frac{n.\overline{n+1}}{2\,N}\,w'.$$

Let s be the length and k the difference of level of the ends of either diagonal.

$$\text{Then stress} = \frac{w's}{k} \cdot \frac{n\,(n+1)}{2\,N} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Example.—To determine the scantling of the main rib of the centre span of the bridge, shown in Plate XXIX.

Where $k = 10$ feet.

" $l = 74$ "

N = number of sections in span = 10 "

travelling load = 1 ton per running foot $= w'$

weight of roadway 280 lbs. per foot superficial.

permanent load on each joint $= \frac{74}{10} \times 10 \times 280$.

$= 20720$ lbs. $= w$

$$\begin{aligned}\text{working co-efficient for deodar} &= 700 \text{ lbs}\\ \text{Whole weight on centre truss} = \text{W} &= 74 \times 10 \times 280\\ &= 207200 \text{ lbs.}\end{aligned}$$

$$\therefore \frac{\text{W}}{2} = 103600 \text{ lbs.}$$

$$\text{and height of truss} = 16 \text{ feet} = h$$

For *stress at crown of rib.*—

$$\text{H} = \frac{\frac{\text{W}}{2} \times \frac{l}{4}}{h} = \frac{103{,}600 \times 74}{4 \times 16}$$

$$= 119787 \text{ lbs.}$$

$$\therefore \text{area of rib} = \frac{119787}{700} = 171 \text{ square inches ,}$$

consequently, a scantling of 10″ × 18″ will amply suffice.

For scantling of tie-beam.—The tie-beam is acted on by a transverse stress due to the roadway as well as the longitudinal stress, formula (4), Art. 116, must therefore be used.

The permanent load = 20720 lbs., and this is equivalent to a bending weight M of 10360 lbs. at each joint; consequently, the formula will stand thus—

$$bf = \left\{\frac{\text{H}}{d} + \frac{6 \text{ M}}{d^2}\right\}$$

$$\therefore 700\, b = \frac{119787}{d} + \frac{6 \times 10360}{d^2}$$

If $b = 10''$, $d = 18''$, nearly;

$\therefore$ required scantling = 10″ × 18″.

A scantling of 10″ × 20″ has been actually allowed to compensate for bolt holes, weak joints, &c.

For *stresses on the diagonal braces*, the formula (3), Art. 123, must be applied.

If the centre pair of diagonal braces are considered, the required data are,

$n = 4$, the braces being situated between the 4th and 5th suspending rods, and $s = 17$ feet.

$$\therefore \text{Stress} = \frac{w \,.\, s}{h} \times \frac{n\,(n + 1)}{2\,\text{N}}$$

$$= \frac{2240 \times 17 \times 4 \times 5}{16 \times 2 \times 10}$$

$$= 2380 \text{ lbs.}$$

As the braces are about 34 times as long as their thickness, one-sixth of 700 must be used.

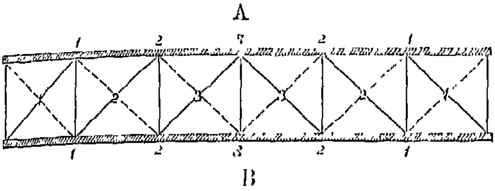
$$\therefore \text{Sectional area of brace} = \frac{2380}{\frac{1}{6} \times 700}$$

$$= 20{\cdot}4 \text{ square inches.}$$

$\therefore$ Scantling required = 5″ × 4½″

6″ × 4″ has been actually allowed.

124. *Weather Bracing.*—The use of lateral bracing is principally to guard against the effects of wind and other disturbing causes, tending to produce lateral flexure in the roadway. The ordinary bracing to resist this action consists of ties and braces similarly disposed to those in the main truss, except that the system being liable to the action of a uniform force in *both* directions, the bracing will consist of two sets of braces of equal scantling, those shown by the full lines resisting the shearing force when the wind is from the direction of A, and those shown by dots when the wind acts upon the other side B.



To find the strain upon the weather bracing.—Let N be number of divisions in the span, and w'' the force of wind upon each joint, s the length of any brace, B the breadth of the bridge between two trusses.

Then, the joints and intersections of the diagonals being numbered from both ends towards the centre, and the braces being designated by the number of their intersection, by Art. 108,

$$\text{Stress upon } n\text{th brace} = \left\{ \frac{N+1}{2} - n \right\} w'' \times \frac{S}{B} \cdots\cdots\cdots (1)$$

$$n\text{th tie (except the middle one)} = \left\{ \frac{N+1}{2} - n \right\} w'' \cdots\cdots (2)$$

$$\text{For the middle tie, stress} = w'' \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

When N is odd, there is no middle tie.

From this it appears that at the middle of the span the lateral braces would be exceedingly light; they might even be omitted in the central panel without injury.

In long spans, this diminution in the size of the braces in the middle adds considerably to the strength, by relieving the bridge of unnecessary weight.

125. *Roadway Platform.*—The usual thickness of the planking for the platform of a bridge with joists is from 3 to 4 inches, the joists being placed at distances of from 2 feet to 4 feet from centre to centre. That thickness has been found by experience to be requisite in order to withstand the shocks, friction and wear, to which the planking is subjected, and is in general much greater than is required for mere strength to support the greatest load with safety. The scantling of the joists is determined in exactly the same method as given in Art. 117; the value of

bd^2 being equated to six times the greatest bending moment, divided by the greatest safe working intensity of stress, see equation (1), Art. 116; the ratio of the depth d to the span should then be first fixed with a view to stiffness, and the breadth computed from the value of bd^2 with a view to strength.

126. *Timber Piers.*—A timber pier for supporting arches or girders may consist of any convenient number of posts, either vertical or slightly raking, and connected together by horizontal and diagonal braces.

Each post should be braced at every point where there is a joint in it, and at additional points if necessary, in order that the distance between the braced points may not be less than about 18 or 20 times the diameter of the post.

Should the pier have a lateral thrust = H, to bear, whether from the action of the wind, or some other cause, the horizontal and diagonal braces are to be calculated to resist the horizontal thrust, in the same manner that the supending pieces and diagonal struts of a diagonally braced girder are calculated to resist the shearing stress, *supposing that shearing stress to be the same at all points, and* = H.

127. Subjoined are various examples of Wooden Bridges actually constructed in India, from the *Professional Papers*:—

Dharwar Bridges.—The Yangul Bridge is the last of several Bridges constructed over the Bunnehulla; a river which runs through the centre of the chief black soil plain of the Dharwar district.

The design of all these bridges is similar; being long timber piles driven into the river bed at short intervals to form the piers, on which whole logs are laid longitudinally as girders, and immediately on these, the road planking and material.

The piles of the bridges average 10 to 12 inches square, being hooped with a 28 lbs. ring, and shod or pointed, with a V shaped strap of 3 × ½-inch iron.

The nuts of the bolts used in these bridges are rivetted instead of being screwed on the shank, this former being found to be the more economical method.

The design adopted has been influenced by several considerations; the character of the bed and banks of the river; the ease with which large timber was procurable from the adjoining forests of North Canara, and the want of skilled labor and trained superintendence to carry out any very elaborate construction.

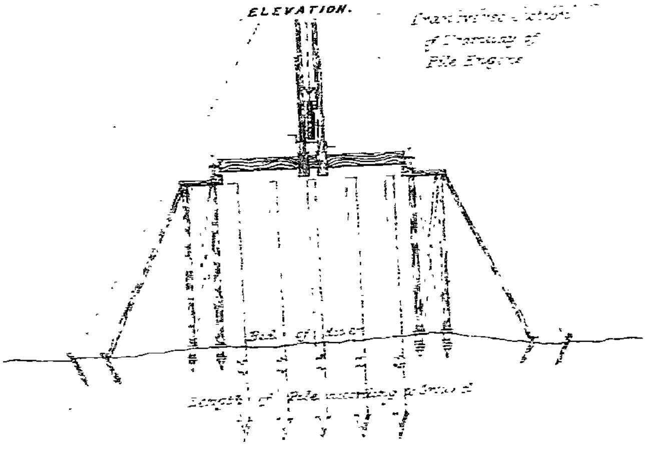
The Pile Engine, which does not differ materially in principle from those ordinarily used, is roughly and economically built; and is well suited to the work it has to do, and to the workpeople for whose use it is intended.

Its chief features are an upright, or standard, formed by two vertical pieces, between the faces of which the monkey works; two longitudinal pieces, into which the foot of this standard is morticed, and to which it is stayed at the back; a frame or platform, from which the above is hung, and on which it runs transversely, motion

PLATE XXVII.

YANGUL BRIDGE

Constructed on the Benehalla River in 1864 —


ELEVATION.
Transverse Section of Framing of Pile Engine
Bed of River
Length of Pile according to Ground

Scale [illegible]

with moorum, and I find by examination that its planking is quite rotten, while that of another timber bridge near it, not *moorumed*, is still quite sound. The age of the former is two years, of the latter four, which makes the comparison still more striking. This defective arrangement is avoided in the Yangul bridge.

The cost of the Yangul Bridge, including approaches, was Rs. 33,594.

The cost of driving the piles per foot was in these bridges, Rs. 2-2, and the cost of each pier Rs. 508.

THE HURROO BRIDGE, LAHORE AND PESHAWUR ROAD.—The Bridge consists of 10 spans of 40 feet each. The piers and superstructure are of timber; the abutments of rubble masonry. The timber work throughout is of heart of deodar, all sap wood being rejected.

Piers—Are shown in full detail in the drawings. Every timber is in one length, excepting only the waling pieces on the pile heads. The lowest pairs of horizontal waling pieces are reduced to 10 × 6 scantling, to admit of timber of the required length being obtained from the Cabool river. The bolts are throughout of round iron ¾-inch diameter.

Abutments and Wing Walls.—Are founded at the depths shown, and are built of coursed rubble with the following exceptions:—The wheelguards are of cut bricks-on-edge, and the parapets are furnished with a cap of cut brickwork, 6 inches thick, laid on edge.

Superstructure.—Corbels on pile heads are 12 inches wide and 10 deep, and are firmly bolted to the tie-beams, each by two bolts of ¾-inch round iron.

The Beams are 10 × 6 scantling, except the last length at each end resting on the abutments, which is 10 × 9, to give depth sufficient to admit of the abutting blocks being countersunk into it to a depth of 3 inches. No joint in a tie-beam within 6 feet of a pier; the drawings show in detail how the joints are made. The pieces all abut against each other with square ends; the keys are of seasoned seesum. Each tie-beam is supported by two ½-inch iron rods.

Vertical Posts over Piers.—Details are given in the drawings.

Straining Beams are secured to the roadway beams by four treenails of 1½ inches diameter of dry khow wood.

Roadway Beams.—Scarfs in roadway beams are made in the places, and in the manner shown. Details are given in the drawings.

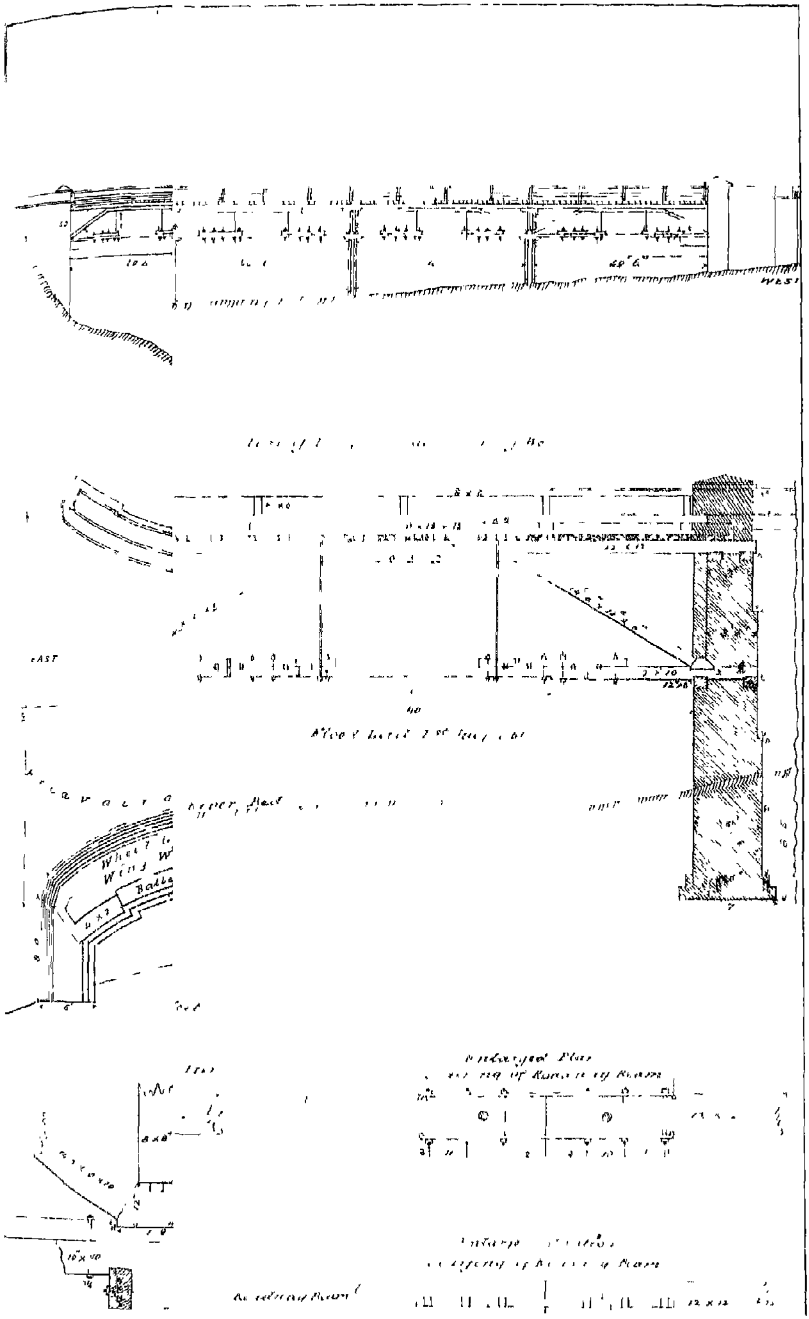
Roadway Planking.—The planks supporting the railing struts are 6 inches thick, no piece being less than 9½ feet in length; they are secured to the roadway beams by spikes 11 inches long. Remainder of planking 4 inches thick, secured by spikes 8 inches long. Each end of every plank rests on a beam and is secured to it by two spikes; elsewhere one spike secures each plank to each roadway beam. The lengths of planking break joint throughout.

Wheelguards are in long lengths, of 10 × 8 scantling. The different lengths abut against each other in each case over a block with square ends, and are kept in position as shown in figure. The hard wood key is of seesum or khow wood.

Wall Plates on Abutments.—The tie-beam is notched out 1½ inches to receive the wall plate.

Metalling is of broken stone.

Painting.—The railings, including verticals and struts, are painted in three coats, of white lead and oil.


49' 6"
WEST
EAST
2 x 10
12 x 12
Wheel
Wind
Ballast
Enlarged Plan
Rocking Beam
Enlarged Section
Rocking Beam
6 x 6
12 x 12

Tarring.—The wheelguards, wheelguard blocks, roadway planking, on both sides and all woodwork, thence to water level, including wall plates, and all touching surfaces, are payed over with pine tar.

Total cost, Rs. 39,789.

BARRA BRIDGE, LAHORE AND PESHAWUR ROAD.—*Specification.*—The Bridge consists of 3 spans, each being formed of three arched girders, as shown in the drawings. The two end spans have a clear waterway of 53 feet, and the centre span a waterway of 74 feet. The piers and abutments are of brick-work; the timber work of well-seasoned deodar.

Wall Plates.—The lower pieces are 10 × 6 inches scantling. The upper pieces rest on them and are 10 × 8 inches scantling.

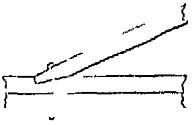
Corbels.—Are notched out and let down on to the wall plates to the extent of 2 inches. The keys connecting the corbels and tie-beams are seasoned seesum or khow wood.

Tie-beams.—Are shown in the drawings in full detail. All treenails are to be baked before they are used.

Abutting blocks.—Against which the arches and the cross braces abut, are of seasoned seesum.

Roadway Beams.—Are let on to the tie-beam to the depth of 2 inches. The beams which project and carry struts to steady the vertical frames are to be secured to the tie-beams by ¾-inch bolts. All other roadway beams, excepting the last over each abutment, merely rest on the tie-beams. They are kept in place, by the 2-inch deep notches at each of their ends, and by the planking which is spiked on to them.

Weather Bracing.—None is provided for in the two end arches: in the centre span two timbers 8 × 6 inches are introduced at each end, secured to the tie-beams by 1-inch bolts and proper joints, as shown; and supported each at its centre by a bolt passing through a roadway beam.



Roadway Planking.—The spikes to be 9 inches long; two spikes to be used at each end of every plank. One spike is to secure each plank to every roadway beam that it crosses.

Wheel-guard.—Different lengths to abut against each other with square ends.

Cross Braces.—To be stepped into the hard wood blocks with tenons 2 inches square and 1½ inches deep, and to be secured to each other, where they cross, by a ½-inch bolt.

Arches.—Full details are given in the drawings. The surface of the planks to be tarred before they are finally put together in the arch.

Railing.—Is secured at intervals to the cross braces and arches.

Vertical Frames.—The posts are bolted to the tie-beams and to the arches, and fit into the cap pieces, with mortice and tenon joints secured by an iron strap.

Painting.—The railings, railing posts, and struts, are to be painted.

Tarring.—The beds of the hard wood blocks, all touching surfaces, where not exposed, surfaces of junction between corbels, wall plates, and tie-beams; and touching surfaces of tie-beam itself, &c., to be tarred.

Tie-rods.—The head to rest on the tops of the arches over an iron washer. Under the nut, a piece of hard wood 12 × 6 × 4 inches, is inserted to distribute the support over the tie-beam. A washer to be inserted between the nut and the hard wood.

Stone Posts.—To protect the ends of the central arch over the abutments; two stone posts of 9 inches diameter are let into the ground.

The centering for building the plank ribs, consisted of a number of long stout timbers (which were afterwards used up as roadway beams) laid at equal distances on the ground, in the direction of radii of the curve, and carefully levelled. Any short spare timbers, not less than 10 × 8 inches, that could be obtained, were then roughly dressed to the required radius on their outer side, and connected together by square lap joints so as to form one continuous curve. These were further kept together by ¾-inch bolts passing through the lap joints and the extremities of the long timbers, into which they were slightly notched to prevent the bolts being bent by lateral pressure. The curved outer face of the short pieces was then carefully dressed and planed to the required radius, and formed a centering, on to which the planks were bent with screw clamps. Notches were cut on the curved surface, opposite each joint in the rib, sufficiently large to admit a wrench, by which the nuts were screwed home. The same centering served for all the trusses; those of least curvature being built first. In such cases it would, however, always be better to raise the centering on brick pillars some 3 or 4 feet from the ground; as this would allow the workmen to fit the lower face of the rib as accurately as the upper. There would then be no need to turn the rib on itself to plane and adjust its lower face—a great advantage—as plank bows are very liable to be damaged by the strains produced by their own weight, if not very carefully supported at their extremities. They should be moved as little, and as carefully as possible before being permanently fitted on to their tie-beams. To prevent the ribs from flattening out, they were kept screwed on to the centering, and thoroughly wetted, for a few days after being bolted together. As the low centering would only admit of this being done to the upper face of the bow, the unequal expansion caused it to warp; and it is very probable, that the tendency so occasioned, may spoil the look of the bridge, when time and weather have loosened the joints of the cross and side bracing.

In order to allow for the straightening of the rib when taken off the centering, the latter was built of a sharper curvature than the arch was intended permanently to retain. The tendency to flatten, is however much less than might be expected, and no difficulty was experienced in keeping the bows of the proper shape. The radii of the centerings were made shorter than the proper radii, by ¼ of an inch to every foot of the intended rise in the completed arch; and in every case this allowance was found to be quite sufficient. 35 feet 6 inches was found to be the least radius to which 3-inch deodar planks should ever be bent; as none but the very best would take that curve. 2½-inch planks would have been employed, were it not that the strength of a laminated arch, as compared with that of a solid rib, diminishes almost in the ratio of unity to the number of layers into which it is divided.

Many different methods were tried for bending the planks, but the following plan which was very economical as not requiring a steaming apparatus, was found less injurious to the fibres of the wood than any other. The planks were wholly immersed in water for eight or ten days; then taken out, placed on edge before a bright chip fire and oiled on both sides until well heated throughout. They were then bent on to a curved gauge, by means of a rack-stick and rope looped over their ends, without giving any signs of straining. On cooling, they retained the form so given them; and by soaking half an hour in water, and repeating the process of heating and oiling, could be fitted on to the centerings with the greatest ease.

It is doubtful, whether iron hoops shrunk when hot over the ribs, would not answer better than bolts to connect the layers of planking. Hoops would not, in practice, be as convenient as bolts, if it were necessary to take out or renew a plank, and might not make so stiff an arch ; but they would not weaken it by bolt holes near the joints. A combination of both would perhaps be best—hoops for the outside and bolts for the inside joints. The joints of an outside plank can never, by means of bolts alone, be prevented from starting from each other and from their underlying planks, after a little exposure to the weather. A broad strap over the joint would quite prevent this ; and the rib would not be weakened by four bolt holes, passing through it at its weakest points.

The following points were noticed in the construction of the tie-beam, which may be of some use. The scarf shown in the drawing might with advantage have been altered to a plain fish-joint with stout strap irons. This was actually done in one of the smaller ribs ; and was found on trial to act better than the scarf, which showed a great tendency to split up at its angles. Hard wood keys 1½ inches square, introduced at intervals between the two pieces of the tie-beam, prevented their sliding on one another under unequal strains, and took the lateral pressure off the connecting bolts. The corners of the notches, cut for the reception of the hard wood abutting blocks, were secured from splitting up under the thrust of the arches, by pieces of angle iron let into the wood.

The bridge was tested by a dead load of (it is believed) 200 lbs. to the superficial foot of roadway ; which it bore without injury. Owing it is supposed, to the strength of the arched ribs not being at first fairly brought into play, the deflection under the half was greater than that under the whole of the load.

CHAPTER XXXIII.

IRON BRIDGES.

128. WE now come to what is by far the most important class of bridges at the present day, and which in Europe have for the last twenty years been rapidly superseding every other description, even for small spans, their strength, durability and (under favorable circumstances) economy, forming a combination of advantages not to be attained by the use of any other material.

Only a few years ago, with the exception of a few isolated instances, such as the bridge over the Goomtee at Lucknow, the Suspension Bridge at Saugor, and a few specimens of no great size near Calcutta, iron bridges may have been said to be unknown in India. The introduction of Railways has now made them almost common, and is to be hoped that European capital and skill will facilitate the working of the iron mines in this country, so that the bridges may be made, as well as set up, in India. Even if this however, is not yet to be expected, the facilities of carriage which are daily increasing, will render the employment of iron bridges for ordinary roads both practicable and economical. More than one has been lately constructed at the Roorkee Workshops, and a respectable firm in Calcutta has offered to send them to any part of the country. Any young Engineer may be called upon to design and erect such structures; and it is important, therefore, that, at least, an elementary knowledge of the subject should be acquired.

129. The preparation of the Material has already been treated of in Vol. I., Chap. VI., and its strength to resist the various strains to which it is subjected in different structures, in Section II., but the following additional remarks will be useful.

Cast-iron is valuable both for economy and strength in all ordinary cases where it is not subjected to jar or vibration. For bridges of small span, say up to 40 feet, cast-iron girders are cheap and good; beyond this, the castings become too large to be depended upon as sound throughout, though large bridges may be made by bolting several castings together. Cast-iron will bear a crushing force of from 36 to 49 tons per square inch, while wrought-iron will only bear 12 to 13 tons, and this points out the applicability of the former to columns supporting a roof, and to similar uses where its compressive strength alone is tried.

Wrought-iron on the other hand resists a force of extension of 16 to 18 tons per square inch, while cast-iron will bear only 3 to 7 tons. Thus cast-iron resists compression better than tension in a proportion of 7 to 1; while wrought-iron resists tension better than compression in a proportion of $1\frac{1}{2}$ to 1. The latter is now extensively used in constructions of almost every description. For roofs and bridges of large span, which combine great strength with lightness, it far surpasses all other materials; while for ships, for cannon, and for numerous other purposes it is rapidly coming into use.

Experience proves not merely that different ores yield different qualities of pig iron, and that these different kinds should be mixed in certain proportions that are known only by practice; but also, that there are many mixtures which will bear a dead load considerably heavier than other mixtures, more highly esteemed and really better; but, if vibration is to be expected, then the results will be reversed. As an ordinary rule, it may be safely considered (says Humber) that about one-half open (No. 1 or 2) pig metal of any reasonably good brand, and one-half good old metal well mixed in charging the cupola, and the girder being ladle-poured, will make as good and trustworthy a girder as can be obtained without going to the expense of using cold-blast iron. The Engineer should remember this in ordering his girder, but, as there are no means of proving the proportion that has really been used after the girders are cast, it should be agreed, instead of naming any particular mixture, that the girder be tested with a dead weight loaded throughout its entire length, equal to *twice* the load it is intended to carry, under which the deflection is not to exceed one-eighth per cent. of the clear span.

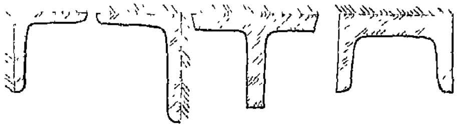
130. The following are the ordinary varieties of wrought-iron which are used in the manufacture of bridges. A *bar* of iron is either round in section, square, or rectangular, in which last case it is called *flat*. The ordinary bar is rolled at once from the bloom, which is passed between grooved rollers accurately defining the shape of the bar.

If square or round, bar varies from $\frac{5''}{8}$ to 3″ or $3\frac{1}{2}''$ in the side or diameter; if flat, from 1″ to 6″ or 7″ broad. If the dimensions fall without these, the bars bear an extra price. Bar cannot be rolled more than 9″ broad.

A *plate* of iron is a physical plane of iron of uniform thickness. The ordinary plates are rolled from faggots, which are bundles of flat bar iron generally from the first rolling, cut all to rectangles of the same size, laid one upon the other, and bound together with a withe of iron wire to hold them together while heating. The alternate layers are of different quality, as hard and soft, unrefined and refined iron. This faggot is rolled to make as nearly as possible a rectangular figure, and the edges are finally sheared to make it strictly rectangular.

Plate varies from $\frac{1''}{4}$ to $\frac{3''}{4}$ in thickness, in differences of $\frac{1''}{16}$; but plates may be rolled thicker than $\frac{3''}{4}$. It has an extra price per cwt. put upon it if it weigh above 3 or 4 cwt., and sometimes if it contain more than about 25 or 30 square feet, or is of peculiar shape. If less than $\frac{1''}{4}$ thick the plate is called *sheet* iron, is more expensive, and generally of better quality.

Angle iron (∠ i) is rolled of various shapes. If of equal sides it is passed through rollers so cut as to roll the iron with the corner upwards: thus when the angle iron (*see* figure) passes through the last pair of rollers the thickness of *both* sides can be equally regulated by one movement of the rollers, nearer or farther from each other. On the other hand, in very unequal angle iron, and in tee and channel irons, the thickness of the broad side only can be altered, since this is then rolled uppermost; the projecting rib must always be of the same thickness with the same rollers.



$2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ ∠ i. $3\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{7}{16}''$ ∠ i. $4'' \times 3'' \times \frac{1}{2}''$ T. i. $3\frac{1}{2}'' \times 2\frac{1}{2}''$ ⊔ i.

The shaded side in each shows the part generally rolled by the upper roller, the rest is rolled against the lower one. The scale is 3″ to the foot.

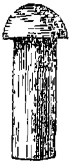
Tee iron (T i.) and *channel iron* (⊔ i.) are other forms of rolled iron.

If angle or tee iron exceed 7 or 8″ in the sum of its extreme breadth and depth, or weigh more than 3 or 4 cwt., then an extra price per cwt. is affixed to them. It can be rolled 16′0 long with ease. In ordinary use it is not well to have a $3'' \times 3''$ $\angle$ i. less than $\frac{3''}{8}$ thick; and a $3\frac{1}{4}'' \times 3\frac{1}{4}''$ $\angle$ i. should hardly be less than $\frac{1''}{2}$ thick.

Generally the price of tee iron is about £1 10*s.* a ton above that of bar; and the price of angle iron and plate about £1 a ton above the same.

All these kinds of iron, if reduced to an uniform section, may be reckoned to weigh 10 lbs. per yard for every square inch in the section. Or, which is the same thing, if it be reduced to an uniform $\frac{1''}{4}$ plate, to weigh 10 lbs. for every square foot of plate.

A *rivet* is formed out of a rod of round iron of the diameter of the intended rivet; one end is raised to a welding heat; a length is then cut off by gauge from the red-hot end, of a proper length to form the rivet, and is immediately formed at one end into a head, either by machine or hand.


A $\frac{3}{4}''$ rivet, $\frac{1}{4}$ size.

Rivet-holes are made by means of a punch, which punches them out of the iron plate, bar, $\angle$ or T iron, while cold.

The *rivetting* of two plates together forms a *joint.* When two or more plates are to be rivetted, they are placed together in the proper position, having their holes exactly over one another, and are screwed together by temporary screw-bolts inserted through some of the holes. The rivets being previously heated red-hot, are then inserted into the holes up to the head, and the small end hammered into a head corresponding to that at the other end of the rivet.

The several kinds of Iron Bridges naturally divide themselves into— 1st, Straight or Girder Bridges; 2nd, Arched, including Suspension, Bridges.

131. CAST-IRON GIRDERS being the simplest in construction may be first considered. Whenever it is only intended for a girder to sustain a fixed load, it is considered sufficient to make it strong enough to bear three or four times the load required, but, whenever it is exposed to constant vibrations, six or seven, and sometimes even ten times, the strength should be given. As a general rule a bridge should be able to support in round numbers *four* times the stationary load, (*i. e.*, its own weight,) + *four* times the greatest moving load that can be brought upon it.*

In the case of a Railway Bridge this latter would be a line of locomotives close together upon each pair of rails. The weights of locomotives vary very much, chiefly according to the difference of power and difference of gauge. They may be said to average 25 tons, and to be 20 feet in extreme length, equivalent to $1\frac{1}{4}$ tons per foot run. The distance, however, between the fore and hind axle-trees will not be more than about 18 feet. Therefore, for bridges under 20 feet span, it would be necessary to allow 2 tons per foot run per line of rails for the greatest moving load; while for those over 20 feet, 1 to $1\frac{1}{2}$ tons per foot would be sufficient.

132. *Deflection under load.*—It has been observed, that if a beam is subjected to repeated deflections, its strength will not be impaired, provided they do not exceed one-third of the *ultimate* deflection, which will vary according to the material used; but, if this is exceeded, breakage must sooner or later take place. A weight passing over a beam at a great velocity will occasion a greater deflection than one at rest, the amount depending not only upon the speed, but also on the rigidity and mass of the structure; hence Railway Bridges are tested first with a maximum dead weight left on for a certain time, and then by passing a heavy train over them at a high speed, the deflection being noted in each case.

The deflection produced in a beam supported at its two extremities, is in direct ratio to the square of the length, and inversely as the depth. Now, it has been proved, that a bar of cast-iron one foot long, and one inch square, may be deflected ·02 of an inch without injury to its elasticity. From this we see that the safe deflection of a cast-iron beam of given dimensions, may be obtained by multiplying the square of its length by ·02 and dividing the product by the depth. The deflection thus obtained would be about one-third the ultimate one, and should never be exceeded in practice. $D = \cdot 02 \frac{l^2}{d}$.

133. *Section of Girder.*—In Vol. I., Chap. X., it has already been shown that when a beam or girder is loaded either permanently or by weights moving over it, it is subjected to a transverse strain, which may be classed under two distinct heads, viz., *compression* and *extension*. It is obvious that a beam being loaded, will, however trifling the deflection may be, form an inverted arch, and, therefore, the top of the beam will be subjected to compression, whilst the bottom has to undergo a certain amount of extension.

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* By the present rules of the Board of Trade, for every cast-iron bridge the breaking weight should be equal to three times the permanent load due to the weight of the superstructure, added to six times the greatest moving load that can be brought upon it.

For every wrought-iron bridge, the greatest weight which can be brought upon it added to the weight of the superstructure, should not produce a greater strain on any part of the material than five tons per square inch.

Between the top and bottom there is a line called the *neutral axis*, upon which there is no horizontal strain whatever. The position of this line depends on the section and material of the girder; for instance, in a square or rectangular section, the neutral axis will be exactly in the centre, provided the strains are within the limit of elasticity.

Now the resistance of cast-iron to compression being six or seven times greater than its resistance to tension, it is evident that it would not be an economical distribution of the metal to arrange it with a square section, but that it should be so arranged as to offer the greatest resistance where the liability to give way is the greatest, viz., at the bottom flange. From many experiments it has been proved that a beam of an inverted T section like this ⊥, and subjected to a fixed weight will resist, before fracture, *four* times the weight of the same beam inverted, thereby showing that the increased mass of metal can be applied with considerably greater advantage at the bottom than at the top of the beam. The strength will also be greatest when the flanges are at the greatest possible distance from each other, and from the neutral axis, and when the latter is in the line of gravity of the section; this object might be attained by making the top and bottom flanges of the same width, and producing the difference in sectional area by making the top flange one-sixth of the thickness of the bottom one, but this would involve not only difficulties in casting, but also a great weakness of the top flange. It is, therefore, usual to give the same thickness to both flanges and to reduce the *width* so as to obtain the required sectional area, which in this case should be made somewhat greater, as theoretically speaking the metal is not distributed to the greatest advantage.

134. *Strength of Girder.*—The formula generally used in calculating the strength of cast-iron girders, is $W = \frac{a\,d\,c}{l}$,[*] W being the breaking weight in tons applied at the *middle* of the girder, a the sectional area of the bottom flange in square inches, *d* the depth of the beam, and *l* the clear span, *c* a constant, which from numerous experiments has been ascertained to be 26. The top flange is made about one-fourth the section of the bottom flange.

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[*] For the investigation of this formula, *see* "Fairbairn on Wrought Iron," p. 236.

This refers to the middle of the girder where the greatest strength is required. But as the load is evidently less effective as we approach the points of support, a less amount of material will suffice as we recede from the centre, and where the bridge is only subject to a fixed load or to a comparatively small rolling load, as in the case of a road-bridge, this diminution is effected by giving the girder a parabolic form in its longitudinal section, the area of the flanges remaining the same.

In the case of a Railway Bridge where the rolling load bears a much higher ratio to the fixed load, the section of uniform strength should be that of a semi-ellipse.*

But as it is better always to work from first principles, a different method of calculation will be given that applies to all materials alike If we call W the uniformly distributed load which the beam will have to bear, and *d*, *a*, and *l*, the same as before, we may assume 1·5 tons per square inch, as the working tensile strain of cast-iron; then regarding half the length of the beam and its depth as a bent lever, we have for the direct strain on the lower flange $S = \frac{W\,l}{8\,d}$† but the girder must be made so as to resist this strain; therefore $S = 1{\cdot}5\,a$. By equating these two

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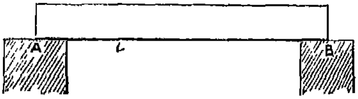
* Vol I., p 178-179.

† Let A B be a beam of length *l*, and depth *d*, supported at both ends. Let w = weight of each unit of length, then $w\,l = W$ = total distributed load $= \frac{W}{2}$ acting at centre of beam



To find the moment of strain at any point C; let $AC = x$ then the weight of $AC = w\,x$ acting at centre of gravity of AC and the moment of this weight about $C = w x \times \frac{x}{2} = \frac{w\,x^2}{2}$. Also the re-action at $A = \frac{w\,l}{2}$ and the moment of this force about the point $C = \frac{w\,l\,x}{2}$. The difference of these moments M = moment of absolute strain at $C = \frac{w\,l\,x}{2} - \frac{w\,x^2}{2}$ (supposing the first to be the greater, which it must be or the beam would break) $= \frac{w\,x}{2}(l - x)$ M is a maximum when C is at the centre of the span or when $x = \frac{l}{2}$, therefore, in this case $M = \frac{w\,l}{4} \cdot \frac{l}{2} = \frac{w\,l^2}{8}$; and if S be the horizontal strain at the centre acting with a leverage $Sd = M = \frac{W\,l}{8}$ or $S = \frac{W\,l}{8d}$. It may also be proved by the parallelogram of forces.

values of S we obtain by transposition the relations between a, l and d, and l being given, the relative proportions of a and d are determined by experience. Of course, the value of S will differ in all materials.

As an example take the following bridge, given in Humber, as one of those on the Great Northern Railway; the section at the centre is here shown, the clear span being 23 feet.

Taking the formula $W = \frac{adc}{l}$ we have in this case a = area of bottom flange = 18 × 1·5 inches = 27 inches.

d = depth of girder = 27 inches.

l = clear span = 23 feet = 276 inches,

c = 26, then

W = breaking weight in tons $= \frac{27 \times 27 \times 26}{276} =$ 68 tons, and the distributed load over the bridge at $1\frac{1}{2}$ tons per foot would be 35 tons, to which add 5 tons for the weight of the two girders, and 4 tons for the superstructure, and we get 44 tons; equivalent to 11 tons at centre of each girder, which is about one-sixth of the breaking weight.

By the other formula, the maximum strain on the lower flange will be $S = \frac{W\,l}{8\,d}$; W being the distributed load = 22 tons, $S = \frac{22 \times 23}{8 \times 2{\cdot}25} =$ 28 tons, and as the working tensile strain of cast-iron is 1·5 tons per square inch, we require 16 square inches to stand this strain, and as we have 27, the girder is amply strong enough, the strain being only 28 tons or 1 ton per square inch.

135. For the construction of the Roadway, one of the simplest ways is to have flag-stones connecting the girders, placed on the lower flanges. It is evident, the girders must be pretty close together, or this would be too weak. Another way is to turn brick arches connecting the upper or lower flanges of the adjoining girders. For railway bridges where the rails are carried on the girders, the intervening spaces may be filled in with corrugated sheet iron; and this is, perhaps, the most economical.

Cast-iron roadway plates for foot and carriage bridges may also be used, say 4′ × 2′ × $\frac{3}{4}$″ for a roadway of a total weight of 200 lbs. per square foot.

We shall examine the methods used for larger structures in treating of Wrought-iron Girder Bridges, to which we now turn as by far the most important, as it has already been observed that there are certain limits beyond which the application of Cast-iron is not advantageous either in point of durability or economy. It is true that Wrought-iron is more expensive than Cast, but this is only relatively so, as the weight of the structure being considerably reduced, what is lost by high price will be to a great extent gained in reduction of weight.

136. The principal kinds of Wrought-iron Bridges are:—

1. The Plate Girder, in which the connecting web between the top and bottom flange is formed by a solid plate.

2. The Tubular or Box Girder, where the roadway is supported by two or more girders in the shape of a rectangular tube, or is carried inside the tube itself.

3. The Trellis or Lattice Girder, which consists in a top and bottom flange, connected together by means of flat diagonal bars or T irons, by which the strain is transferred from the centre to the piers, the roadway resting on the top or being suspended from the bottom.

Plate Girder.—The flanges are made of plates of iron rivetted together by Wrought-iron bolts. The connecting web is also of plate iron. The angle irons connect the web and flanges together; and the thickness of all three depends on the size of the girder and the weight it has to carry. In all girders it is evident, there will be a tendency in the flanges, to approach each other when the weight is applied, and the chief use of the web is to keep the flanges in their places.

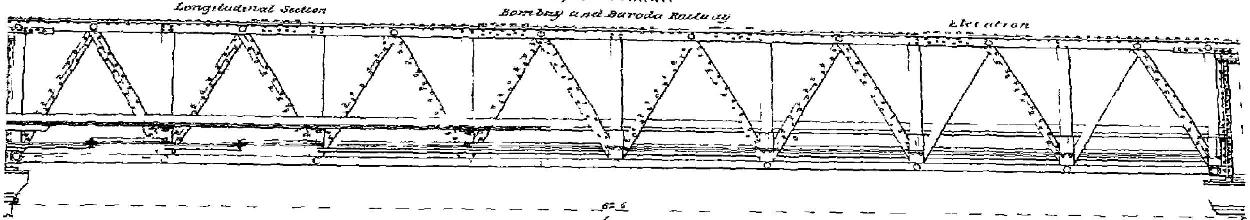
In order to strengthen the web, struts or stiffening plates (as they are usually termed) are fixed at intervals along the whole length of the girder, at right angles to the flanges, and are of such section as well best resist the action of compressive force.

As to the proportions of this girder, it has been found by experiment and calculation that the most satisfactory proportion for depth is one-twelfth the span. The compression or upper flange must not only be made of sufficient area to resist the crushing force, but must also be of such form as will resist the tendency to buckle. The resistance of wrought-iron to tension being, as said above, about one and a half times its resistance to compression, the sectional area of the top flange should theoretically be half as large again as that of the bottom flange; in practice, however, it has been found more economical to let the connecting web and its stiffening

PLATE XXX.

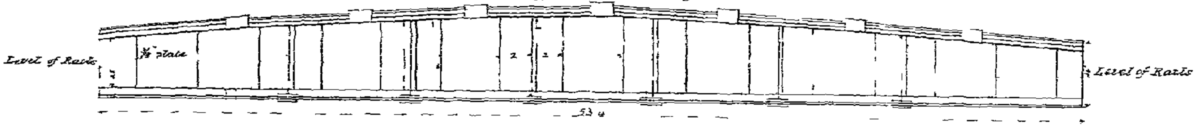
IRON BRIDGES.

Taptee Viaduct
Bombay and Baroda Railway



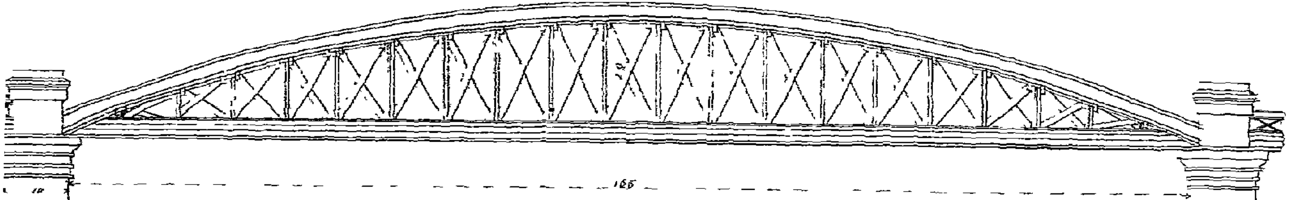
Scale 8-4 equal to 1 inch

Wrought Iron Plate Girder
South Staffordshire Railway



Scale 10 ft equal to one inch

Bowstring Girder
Bridge over the Shannon



Scale 21 equal to one inch

plates sustain part of the compressive strain, and to make the upper flange only about one-sixth larger than the lower flange. A variety of sections are used in different cases, and some of the most ordinary ones are given in the Plate.

Girders have been constructed with wrought-iron webs and bottom flanges, and cast-iron top flanges, in order to take advantage of the superior strength of cast-iron to resist compression. But the objections to this are—1st, We may obtain unsound castings; 2nd, Cast-iron ruptures without any warning; 3rd, It will not bear vibration so well as the other; 4th, The expansion of the two metals by change of temperature is unequal, and might cause unlooked for strains.

137. *Strength of Girder.*—Now to calculate the strength of these girders, we may either employ the same formula as before, $W = \frac{a\,d\,c}{l}$, simply altering the value of the co-efficient C, from 26 for Cast-iron, to 75 for Wrought-iron.

Or, we may take the other formula $S = \frac{W\,l}{8\,d}$; where S = direct strain on one flange, l = clear span, and d = depth, W = total uniformly distributed load. Whence we get the value of S, and as the girder must resist this strain, we take S (or its value) as equal to a (sectional area of flange) multiplied by safe working strain per square inch, which for wrought-iron is 5* tons. Hence we get the value of a, and must arrange our plates accordingly; d, as in the case of cast iron girders, should be one-twelfth span.

To apply the above formulæ—let us take a bridge given in Humber, as one of those on the South Staffordshire Railway, the section of which at the centre of the girder is shown in Plate XXXI., *Fig.* 1, the clear span being 51 feet 4 inches.

Here, taking the formula $W = \frac{a\,d\,c}{l}$, we have for the value of a;

$$\begin{aligned} \text{2 plates} &= 22'' \times \tfrac{1}{2}'' = 22'' \\ \text{2 angle irons} &= (3\tfrac{1}{2}'' + 3'') \times \tfrac{1}{2}'' = 6{\cdot}5'' \\ \text{Total, ...} &\quad 28{\cdot}5'' \end{aligned}$$

$$d = 6',\ c = 75',\ l = 51'{\cdot}4'' = 616''.$$

$$W = \frac{28{\cdot}5 \times 72 \times 75}{616} = 250 \text{ tons, nearly.}$$

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* Or 4 to 4½ tons in the case of rivetted plates to allow for weakness caused by rivet holes.

Now the total weight on each pair of girders would be—

	tons.	cwts.
Weight of wrought-iron on each span, $\frac{47}{2}$	23	10
„ timber in platform and longitudinal bearers, ...	9	7
„ rails, ...	1	3
Distributed load at 1¼ tons per foot run, ...	65	0
Total on each pair of girders =	99 tons,	

which is equivalent to 25 tons at centre of a girder, only one-tenth of the breaking weight.

By the other formula, $S = \frac{Wl}{8d} = \frac{50 \times 52}{8 \times 6} = 54$ tons, nearly, requiring an area of 13·5 square inches, at 4 tons per square inch; and we have 28 inches, ample strength, the real strain being only 2 tons per sectional inch of bottom flange.

138. As to the *Roadway*, it is evidently always best to have the main girders supporting the rails directly when the intermediate spaces can be filled up by any of the methods mentioned for cast-iron girders, but as this would evidently only be applicable to small bridges, the usual arrangement is to have cross girders resting on the main girders, and about 3 feet apart, over which longitudinal sleepers carrying the rails are bolted down. These cross girders are somtimes of cast, but generally of wrought, iron, and the section may be similar to that of the main girder but smaller. The same formulæ apply as above in calculating their strength, the load on each cross girder being the width of the bridge multiplied by distance between the cross girders and by the load per square foot.

The cross girders may be fixed on the top of the upper flange or on top or bottom of the lower flange. In the former case the connecting bolts need only be strong enough to ensure the stability of the platform. In the latter they will have to resist a tensile strain equal to the total load on the cross girder. Thus, if the load on any cross girder be 20 tons, the total area of all the bolts or rivets by which it is suspended from the main girders, must in no case be less than 4 square inches, and in most cases twice this area should be allowed.

In calculating the strength of any bolt from its sectional area, it is of course assumed that the bolt itself will be drawn in two before the thread is stripped. This question will be discussed further on.

Another and very common mode by which the cross girders may be conveniently connected with the main girders, consists in attaching them to the *webs* of the latter by means of angle pieces or brackets, which are fastened either to the webs of flanges of the two girders or to both (shown in Plate XXXI.)

139. In erecting straight girders it is usual to build them with a slight *camber*, from the ends up towards the centre, so as to allow for deflection. The amount of this deflection may be calculated beforehand in designing the bridge by the formula $D = 0{\cdot}000028 \frac{W l^3}{a d^3}$, where W = total weight in tons, l the clear span, and d the depth of the girder; D = deflection at the centre of the span.

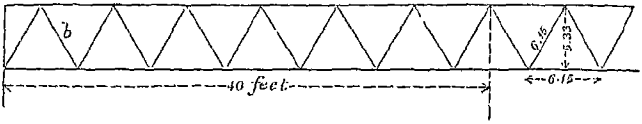
140. *Tubular Girders* are only varieties of plate girders, and have already been noticed in Vol. I, p. 176. A tubular girder consists of two plate girders, in which the top and bottom flanges are so broad that they meet over head and down below. In the Britannia and Conway bridges, and that over the St. Lawrence, the bottom flange forms a platform for the roadway which runs inside the girder, and the flanges are made cellular for the sake of stiffness. In other bridges of this class the roadway is supported by two or more tubular girders, which, of course, are not so large as those which have to carry the roadway inside them; both of these are only applicable to large spans. The calculations are the same as for plate-girders, and need not be entered upon here.

141. Of *Trellis or Lattice Girders* there are several forms. The simplest are those known as Warren's patent; they have been largely used on Indian Railways, but have of late grown into disfavor, chiefly because the vibration of a heavy rolling load has been found to loosen the connecting bolts, and the failure of any one joint would seriously imperil the safety of the whole structure. Combining, however, as they do the important elements of economy, portability and simplicity of construction, they are likely to be extensively employed in this country, if only for road bridges.

A *Warren's Girder* consists of a line of cast-iron tubes on the top to resist compression, and a line of wrought-iron flat links or chains along the bottom to resist tension. The intermediate space or depth of the girder is filled up by a series of struts and ties of cast and wrought-iron, placed alternately, so as to form with parts of the top and bottom a series of equilateral triangles; the roadway may be arranged at the top or bottom, or any intermediate points. If a = length, and s = strain on diagonal, W the uniformly distributed load, d, l and S being the same as before, then at the centre, $S = \frac{Wl}{8d}$, as before, and $s = \frac{Wa}{4d}$, which will be transmitted uniformly from the point of application of the load throughout all the diagonal of the girder, the nature of the strain on each successive diagonal being alternately compressive and tensile.

And at any other point, distant x from the abutment, we shall have (*vide* page 134) $S = \frac{W}{2dl}(lx - x^2)$, and for any other diagonal, $s = \frac{Way}{dl}$, y being the distance of the *foot* of the diagonal from the centre of girder when W is on the top. If W is on the bottom, y is the distance of the *top* of the diagonal from the centre.

Calculation of strain on Warren's patent girder, under load at centre of 250 tons, equivalent to a uniform load of 500 tons. Span, 80 feet.



The span of 80 feet is divided into 13 equal spaces, forming equilateral triangles. This gives each side of the triangle 6·15 feet, and the depth of the girder 5·33 feet.

Then $l = 80$.
$d = 5{\cdot}33$.
$a = 6{\cdot}15$.
$W = 500$ tons.
S = Horizontal strain at centre.
s = Strain on a diagonal or lattice bar.

$$\therefore S = \frac{Wl}{8d} = \frac{500 \times 80}{8 \times 5{\cdot}33} = 938 \text{ tons.}$$

$$s = \frac{Wa}{4d} = \frac{500 \times 6{\cdot}15}{4 \times 5{\cdot}33} = 144 \text{ tons.}$$

This is uniform throughout the whole length, being alternately compression and tension on the alternate bars.

The horizontal strain at any point is $S = \frac{W}{2dl}(lx - x^2)$; x being distance of point from the abutment.

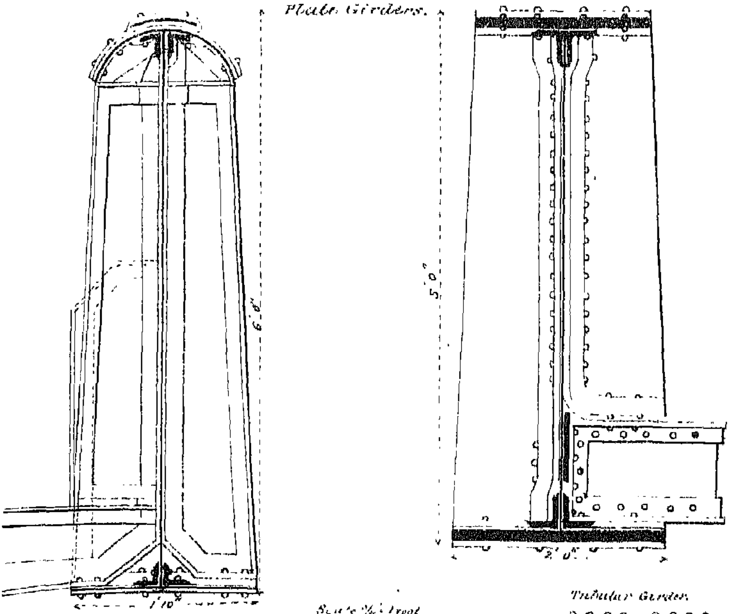
The strain on any diagonal b is

$$s = \frac{W}{dl} a y$$

IRON BRIDGES.

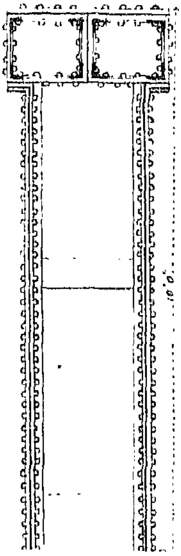
Cross Sections.

Plate Girders.

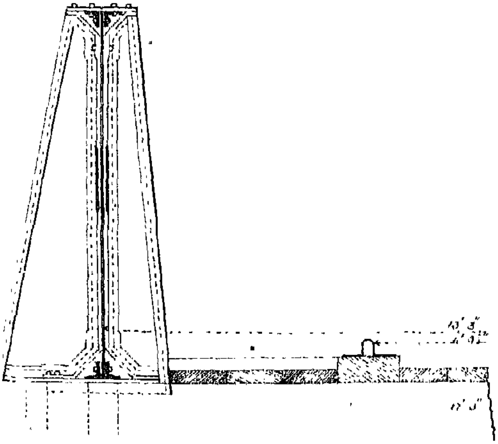


Scale ½ 1 foot

Tubular Girder.



Warren's Girder.



and if we consider the load to be on the top of the girder $y = 33{\cdot}82$ and

$$\therefore s = \frac{500 \times 6{\cdot}15 \times 33{\cdot}82}{80 \times 5{\cdot}33} = 244 \text{ tons.}$$

If the weight were attached along the bottom, y would be $36{\cdot}9$, and

$$s = \frac{500 \times 6{\cdot}15 \times 36{\cdot}9}{80 \times 5{\cdot}33} = 266 \text{ tons.}$$

142. Other forms of Lattice Girders have lately been much employed both in India and elsewhere, especially for large spans, as in the case of the two great bridges over the Jumna at Allahabad and Delhi. The top members usually consist of a series of wrought-iron boxes or cells; the bottom members of a series of bars laid side by side, and bolted together; the strength of both increasing from the ends to the centre where the strain *is the greatest; the diagonal lattice bars on the contrary increasing* in section from the centre to the ends to which the strain is eventually transferred. The light and graceful appearance of the lattice girder, and the ease with which it can be taken to pieces and put together again, while any defective part can be easily repaired, make them great favorites with Engineers; though it is said they are neither so strong, stiff, nor economical, as plate or box girders. The calculations of strains are similar to those for Warren's Girders.

143. The strains on the several parts of these as well as other Iron Girders may be also worked out from the formulæ given in the last chapter for Wooden Bridges; to which the reader is referred.

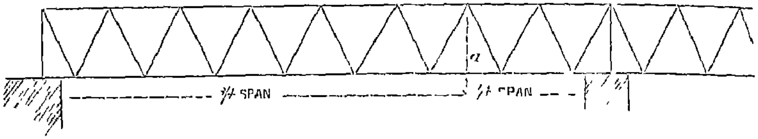
144. *Continuous Girders.*—The advantage of the continuous arrangement in a series of girders has been already explained in Vol. I., Art. 191.

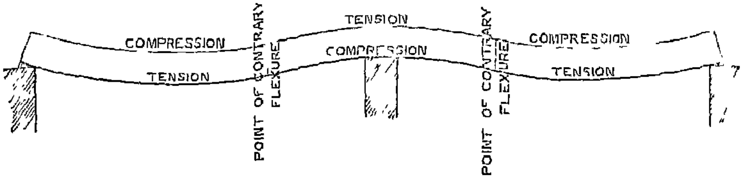
In a girder of this description, extending over two spans, the portion next the abutment for the length of three-fourths of one span, should be treated as if a detached and independent girder with the loading which is due to its length, and the strains upon each of its parts should be calculated accordingly.

The remaining one-fourth should be treated as a cantilever (*i. e.*, a beam fixed at one end only) projecting from the central pier, and supposed also to be detached and independent. The strains induced upon it are as follows:—One-half of the total weight of the supposed separate girder above mentioned (or the weight of three-eighths of one span), is taken as placed at the extremity of the cantilever at *a*. In addition, there are the strains from the loading upon the cantilever itself, and the sum of these double effects gives the total strain upon each portion of the supposed cantilever.

If the distance of three-fourths of the span from the abutment fall intermediately on a bay, it will be better, for convenience of calculation, and for security of construction, to include that bay in the separate lengths both of the girder and cantilever as supposed.

The point *a* where the supposed girder and cantilever unite, is usually called *the point of contrary flexure*, because, a loaded continuous girder assumes a curved outline which is concave from the abutment to this point, and convex from thence to the central pier, as shown in the figure.





It is also to be especially noted that the horizontal strains over the pier become tensive in the upper flange and compressive in the lower between the points of contrary flexure, as shown in figure; the portion treated as a cantilever having its strains reversed as compared with those of a girder.

When one of the spans is more heavily loaded than the other, (which takes place, for example, in the case of a railway train when occupying one span only during its passage of the bridge,) the position of the point of contrary flexure is brought nearer to the central pier, and the portion of the structure next the abutment must be calculated as a girder of greater length than three-fourths of the span. The following formula will give its length in this case:—

Let W be the weight of the heavier span;
W^1 be the weight of the lighter span;
And L the length of one span;

Then $\frac{7\,W - W^1}{8\,W} \times L =$ Distance from abutment to point of contrary flexure.

This distance should be taken in practice as the length of the girder portion next the abutment, of which the strength should be calculated accordingly. But the length of the cantilever portion must still be estimated as one-fourth of the span, since it becomes so when both spans are fully loaded. In fact, the point of *contrary flexure* is varied in its position by unequal loading, and both girder and cantilever must be made suitable for the the extreme variation in each case.

In the case of a continuous girder of three or more spans uniformly loaded, the distance of the point of contrary flexure is altered in the first opening to four-fifths of the span instead of three-fourths; and in the the middle span or spans, the length of the cantilever portion is increased from one-fourth or twenty-five hundredths to about twenty-eight hundredths of the span :—the remaining portion of forty-four hundredths of the central span being treated as a detached girder as before described. In other respects the girders are treated similarly to those over two openings, as above described.

145. The ends of girders when erected usually rest on cast-iron bed-plates fixed in the abutments; and, to allow room for the expansion and contraction of the mass of metal from changes in the temperature, one end either rests on cast-iron rollers, or it is fixed on to the bed-plate by *slotted* holes.

The parts of a girder may either be put together into one piece and the whole raised or rolled on *to* its place, or a timber scaffolding may be erected on which the girder may be gradually built up.

146. The following is a description of the Lattice Girder Bridge over the Jumna at Allahabad, on which the East Indian Railway is carried:—

The design provides for a double line of Railway and Roadway, the rails being carried on the tops of the Main Girders at a height of about 17 feet from the surface of the roadway. Each span was intended to consist of two distinct bridges, placed side by side, and each bridge was designed to carry a railway and roadway ; the structure, however, has only been completed for a single line, though the Masonry and Iron superstructure of the piers have been erected for both. The Main Girders, of which there are two to each bridge, are composed of the following parts, viz., a top compressive member formed of wrought-iron boxes or cells, a bottom tension flange of wrought-iron bars or links, and a web which is of the triangular principle, and consists of a series of wrought-iron struts and ties, the former of which are placed in a vertical position. The cross girders for the upper roadway are placed at distances of 1 foot 6 inches apart, and are of the construction shown in figure ; those for the lower roadway, are placed in pairs at a central distance of 4 feet 6 inches between each pair. The platform of the lower roadway, which is formed of a double thickness of 2-inch planking, is carried on 4 wrought-iron continuous longitudinal joists, which rest upon the cross-girders just mentioned, these joists are braced together on the under side by wrought-iron bars 3 inches wide, and ¾-inch thick.

Total Weight of Bridge.

	Tons	Cwt	Qrs	Lbs
15 Girders, ...	3,769	15	2	14
14 Platforms, ...	23	16	0	0
7 sets of bed-plates, with roller arrangements, .	124	4	2	7
7 sets of bed-plates for fixed bearings, . . .	99	6	1	0
1 for land pier, , ...	9	15	0	0
1 for land pier, ...	7	19	1	21
Weight of superstructure for one line of railway and roadway, ...	4,031	16	3	14
Weight of iron work in piers, ...	159	4	0	0
Total weight of ironwork in bridge as executed, .	4,194	0	3	14

which, for a length of 3,330 feet, gives a total weight of iron per foot-run of 1·235 tons.

The following are the principal points in the Specification:—

The whole of the *Wrought-iron* used for the work, is to be free from scales, blisters, laminations, and all other defect. No plates, bars, or angle-irons, will be approved which are found to exceed, or fall short, of the specified weights and dimensions, more than 5 per cent.

The *bars*, and all parts of the girders whatsoever, which may be subjected to tension, are to be capable of bearing a tensile strain of, at least, 20 tons on the square inch of section, under the concussion of a blow struck with a heavy hammer.

The *rivets* are all to be of the best quality of Staffordshire rivet-iron.

The *bolts* and *nuts*, and the *horizontal braces*, are to be made of the Monk Bridge "best," or of Bradley's **S. C.** crown iron, or of such other iron of equal quality, as shall be specially approved by the Engineers.

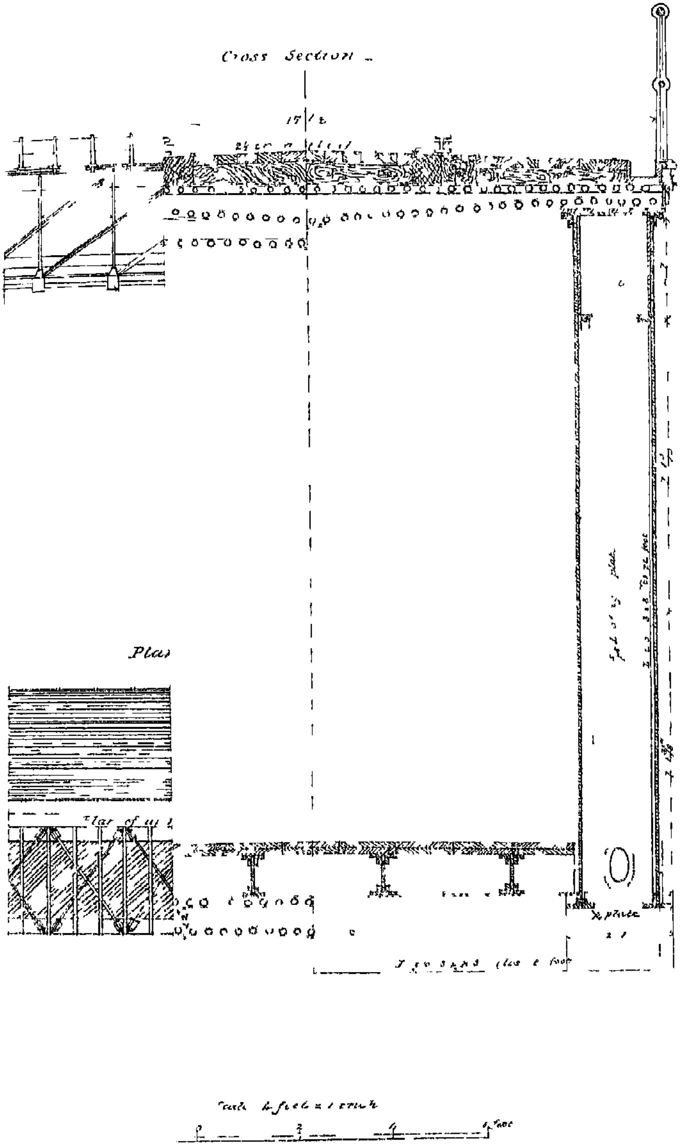
The *frames of the expansion roller bearings* are to be forged from Low Moor, or Farnley, or the best Monk Bridge iron.

All the *Castings* are to be clean, sharp, true to form, and free from air-holes or other defects. The *bed-plates* and *rollers* are to be cast from a mixture specially selected for hardness.

The *bolt-holes* in the bottom bars, and in the diagonal ties, are to be made as follows:—Holes not more than 1⅛ inches in diameter, are first to be punched through the bars, as nearly as possible over the centres of the finished holes, their position having been accurately marked off with a template. The bars, in sets of from six to twelve, are then to be stacked on, and bolted firmly, to the bed-plate of a boring tool, made or adapted specially for the purpose. In this position all the holes are to be bored, without the bars being shifted from the bed-plate, the boring tool being passed through the holes punched in the bars, and guided in steel bushes, both above and below the tool.

All *angle-irons* whatsoever, not expressly excepted, are to be in single lengths, without welds or joints. In the struts and intermediate girders, they are to be carefully bent at a sufficient heat, to the required form without being cut.

PLATE XXXII.


Cross Section.
Pla
Plan of u
½ plate
Scale 4 feet = 1 inch
0
2
4
6 feet

The *plates of the horizontal boxes* are to be in one length, without joints; and throughout all the girder work no joints or joint-plates will be permitted, beyond those shown on the drawings.

The *lugs* by which the horizontal braces on the girders are affixed to the top boxes are to be of forged scrap-iron; after being drilled to take the rods, they are to be rivetted on the boxes accurately in the line of the braces.

The *braces* themselves are to be rods of 1¾ inches in diameter for their general length, but having pieces of rod of larger diameter welded on their ends, to take the screwed portion without reducing the section below that due to a diameter of 1¾ inches. They are all to be screwed at each end for a length of not less than 6 inches, and provided with double hexagonal nuts.

Lower Roadway.—*1st.* Four rows of continuous wrought-iron joists are to be laid from end to end of the bridge, to carry the lower roadway. The outside rows consist of bars 7 × $\frac{5}{16}$ with two angle-irons at each edge, each 2½″ × 2″ × ¼″. The lower flange is strengthened by a plate 10″ × ½″, also running the whole length of the bridge. These joists, with the 10″ plate rivetted to them, are to be sent out complete in 20 feet lengths, the connections between the plates being made as shown.

The intermediate joists consist of bars 8″ × $\frac{5}{16}$″, with two angle-irons, 2½″ × 2″ × ¼″ at each edge, to be made up in 20 feet lengths as before.

All these lengths are to be so arranged as to break joint with each other.

The cross-girders are to be punched out where these joists cross them, so that they may be rivetted together in India.

These joists are to be braced together on the underside, by wrought-iron bars 3″ wide, by ¾″ thick.

2nd The vertical struts are to be connected together at the lower ends, with plates ⅜″ thick, 15″ deep, and of such width as will fill up the distance between the vertical angle-irons of the strut rivetted to the struts with four ¾″ rivets on each side.

3rd. The end bars of the lower member of the girder are to be stiffened by the insertion between each pair of ½″ bars, of a bar 3″ × 1″. All these bars are to be rivetted together.

The pairs of bars on each side of the girder are to be further connected together by 3″ × ¾″ bars forming a bracing as shown. None of the rivetting is to be executed in this country, except what is necessary to form the intermediate bars into a bracing.

Accuracy required.—It is to be expressly understood, that as a rule, the greatest possible accuracy is to be attained in every part of the work, the object being to facilitate the erection of the bridge in India by perfection of workmanship in this country. It is therefore intended that all similar parts shall fit indiscriminately in all similar places and in any span. To ensure this, every similar piece is to be tested on completion, as to the accuracy of its form and dimensions, in a gauge-test, and all those that do not correspond with such gauges will be rejected.

Testing.—Every span of the bridge is to be erected, rivetted together, and finished complete in every respect, except as regards timber-work, on the contractors premises, so that it may be tested under load. For this purpose it is to be put together upon a timber platform, as specified in the following paragraphs, and bearings are in addition, to be provided at two ends to carry the girders when the wedges beneath the platforms are withdrawn.

These bearings are to be of solid masonry, built upon concrete, and (if necessary,) piled foundations, to prevent the possibility of settlement during the testing of the span.

Should any settlement take place whilst the whole or any portion of the load is on the bridge, the contractors will be required to remove all such load, to reinstate the bridge in its proper position by means of the platform wedges, and to recommence anew the testing. The load to be placed is 450 tons of pig-iron, ⅘ of which are to be put upon the upper roadway, and the remaining ⅕ upon the lower roadway. It is to be laid upon temporary planks of sufficient strength, and distributed uniformly over the roadway.

On the receipt by the contractors of the Engineer's certificate of the satisfactory completion of the testing, the temporary rivets are to be cut out and the span taken to pieces, packed, and delivered for shipment.

The girders are to be erected on timber platforms, and must rest immediately on cross cills, with carefully-made folding wedges of hard wood beneath each cill, the cills and wedges being sufficiently close to admit of the girders being readily raised or lowered by driving or withdrawing the wedges.

These cills are to be carried on piles, if the nature of the ground renders piling advisable, or if not, they are to be secured by other means from the slightest settlement.

The required camber must be carefully given to the platform in the arc of a circle, the chord or camber in the centre being 4½ inches.

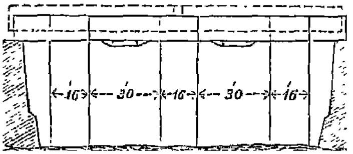
Painting.—The whole of the materials delivered under this contract are to be painted with two coats of good zinc paint, or of Woolston's Torbay paint, of any color the Engineers may desire, one to be laid on as soon after the formation of the parts, and the other subsequent to the taking to pieces of the parts, after their temporary erection.

The superstructure of this fine bridge was designed by the Messrs. Rendel, and executed at the Canada Iron Works, Birkenhead.

The following refers to another Bridge on the same line of Railway:—

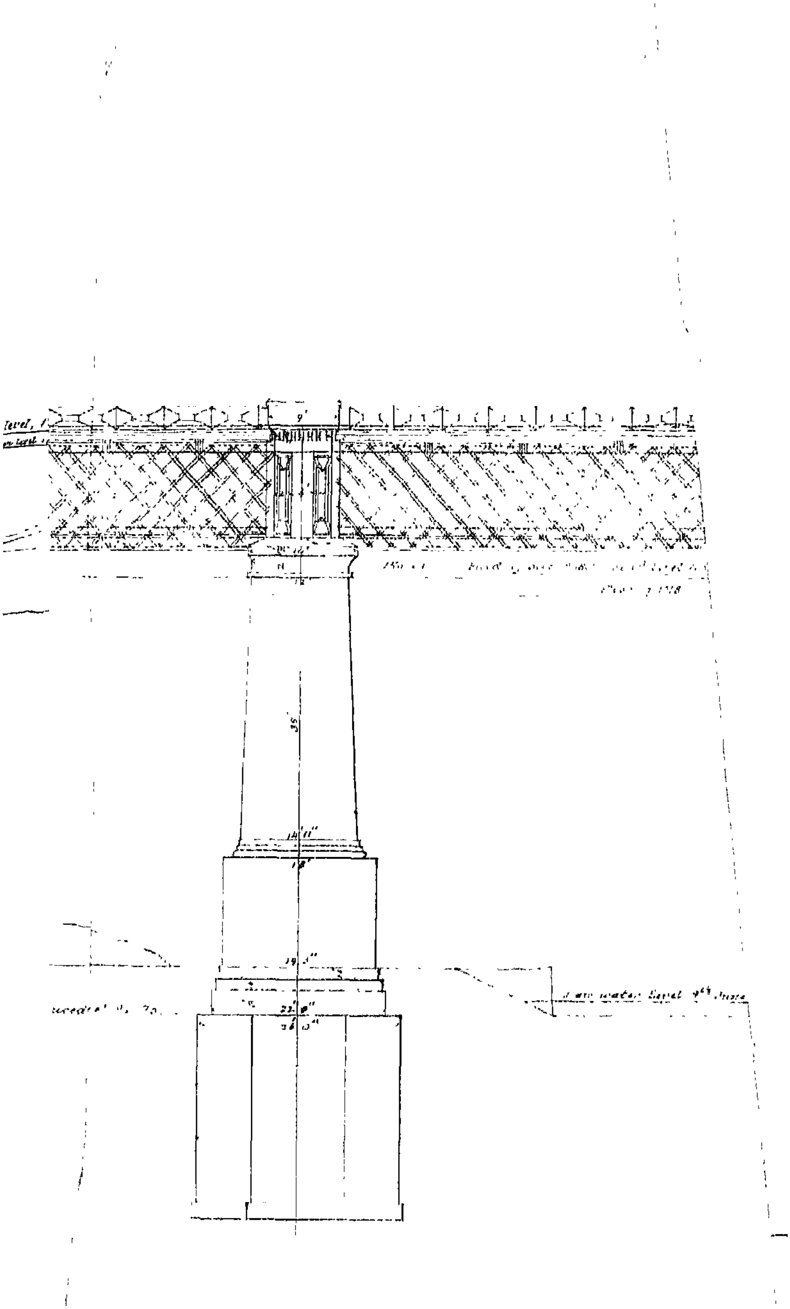
Tonse Bridge.—The lattice-girder was selected by Mr. Rendel, the Consulting Engineer to the Company in England, and the ironwork of the bridge, weighing about 1,200 tons, was constructed by the firm of Westwood, Baillie, Campbell and Co., of Millwall. The Bridge consists of seven spans of 150 feet, and the thickness of piers was 12 feet only at the narrowest part.

The ironwork was erected on a double row of wedges supported by a scaffolding of sawn timber, consisting for each span, of trestles about 60 feet in height, an elevation of which is subjoined; these trestles carried six double rows of whole timber balks as longitudinals, the trestles being arranged in pairs, as shown in sketch, in which the outline of the girder is represented by the dotted lines.



At the level of the top of the piers were four rows of longitudinals, the outermost pair of which carried a line of rails on which worked a travelling crane striding across the girder. The inner pair of longitudinals at the lower level carried the tension links of the girder, and the upper pair of longitudinals carried the compression member, or "top-boxes."

The *trestles* were, in the first two spans erected, supported by piles of sâl timber,


Level
9'
35'
14'11"
18'
19'3"
22'8"
26'0"
Low water Level

as shown in the drawing, but all the spans besides were erected on stages resting on a row of about 60 sleepers under each sill. The thread of the stream runs through No. 2 span (reckoning from east to west), and it was consequently necessary to fill this channel up and divert the river through an artificial cut of 70 feet wide, passing under one of the spans already completed, a new temporary bridge being erected over the cut for conveying the supply of materials. As it was desirable to save time, the sleepers were laid on the earth as soon as it was filled into the natural channel, and while it was in a state to barely support the weight of the coolies who filled it in. A bed of 18 inches of dry sand was placed under the sleepers, which were beaten down with heavy mauls before the sills of the stage were laid. The stages were erected with derricks, of which there were five, each of 75 feet or more in height, working two on each side of the stage, the fifth being much stronger and capable of hoisting 4 tons to a height of 80 feet. This derrick proved very efficient, the great difficulty being in raising it on end. This was done by two tackles acting from the top of one of the piers and secured to the derrick at one-third of the length from its upper end. These tackles consisted of a pair of two sheaved blocks with double purchase crabs on the falls.

The larger derrick was used for sending up the longitudinals of the stage, the travelling crane, the stones, weighing 274 tons, each, on which the bed plates of the girders, rested, and the heavier parts of the girders themselves. The guys were secured to piles 15 feet long, driven into the river bed where required. The smaller timbers of the stage were sent up "by the run," *i. e.*, by a gang of men running away with the falls of the tackles. Above three weeks were required to erect the stage for one span. The longitudinals immediately under the tension-links over the 30 feet bays, were strengthened by trusses (shown in page 141) of wrought-iron with cast-iron saddles. These had been tested up to 19 tons for each longitudinal of 24 inches by 12 inches, and were thus amply strong to carry the portion of the weight of the girder imposed on them previously to its completion.

The girders rested on sleepers of Baltic fir or sál, under which were folding wedges of 3 feet long, the camber or upward curve being given to the girder by additional wooden packings of different thicknesses under the wedges.

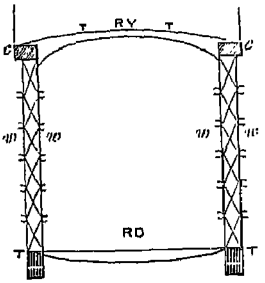
The spaces between the longitudinals were covered with the iron flooring plates, to be used in the upper roadway, so as to form a continuous platform from pier to pier. Several fatal falls from the stages having taken place among the workpeople, a net of ropes with meshes about 1 foot square was suspended from the under surface of the flooring of one span. This however was abandoned, when the rivetting commenced, owing to the danger of fire. Each frame of the spans was put together on a plaster floor on the river bank, and each piece numbered similarly on each side of one of the joints, so that when the frames were taken apart for removal into the river bed, they might readily be selected. When the girder was able to stand alone, the stages were pulled down by the derricks used in their erection, the demolition of each stage occupying only about eight days. A large quantity of "cheer" timber from the Himalayas was used in the staging; it much resembled white Swedish pine, and was rather a spongy sappy wood, not likely to be very durable. It was no doubt in an unseasoned state, which may partly account for the above defects. The rest of the stages was either of round sál spars, or squared Baltic or American fir.

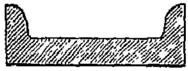
As the details of the *Girders* may not be very easily discernible from the drawings, a general description of them may be useful in enabling the reader to understand the method of their erection.

They consist, like all framed girders, of parts constructed to resist compression at the top, and of a set of struts, which from their inclination convey the weight of the girder and load, from the top member towards the piers, the vertical part of this stress being again transmitted by a set of tension bars from the lower to the upper member, again removed by the next set of struts a stage further towards the piers, and so on to the last struts, which bear against strong upright columns of boiler-plate on the tubular or "box" principle. As the strain on the struts and ties increases from the centre of the girder towards the ends, their scantling is gradually increased, there being four classes of these bars in each span.

The struts and ties intersect each other at right angles, thus forming a lattice wall of which the top-boxes may be called the coping, and the chain of links securing the struts from parting at foot, may be called the foundation.

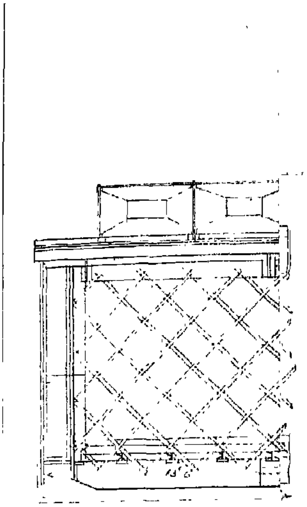
Two pairs of such walls make up one span, a floor being laid at the bottom of the walls to carry the carriage-road, and another overhead to carry the railway. The lower member, by which the bottoms of the struts are tied together, consists of a double layer of flat bars or links placed on edge and united by bolts with each other, and with outer plates to which the struts and ties are rivetted. These links are not flexible like a chain, but have their ends rigidly connected by the bolts. This double line of links increases in strength from the ends to the centre of the girder, the number of links being greatest at the centre, and at the ends reduced to merely the two outside plates carrying the lattice bars. The lattices are strengthened transversely by a bracing inserted between the walls, which form the sides of the span and which are marked *ww* in the marginal sketch. In this sketch the bracing, which is of a zigzag form is indicated; RY is the railway, *cc* the compression member or "top-boxes," TT the tension links or lower member, RD the road, and *ww* the walls of lattice work, or "webs" of the girder. The bars composing these webs or walls are of the "channel" section, (marginal sketch,) rivetted back to back at the intersections. The top boxes are simply boxes of boiler-plates, increasing in strength from the ends to the centre, and secured together by flanges rivetted with inch rivets; the ends of the boxes and the flanges are planed to ensure a good butt.





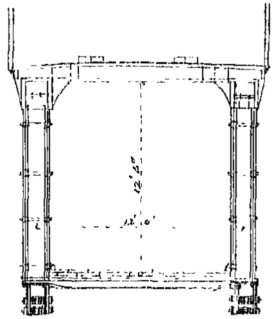
The girders rest on blocks of cast-iron hollowed out underneath, and bolted to the bottoms of the "end standards" or vertical boxes. These blocks rest on "saddles" of cast-iron fixed at one end of the girder, so as to admit of a movement there in a circular or vertical direction only, while at the other end of the girder the saddles run loosely on cast-iron rollers, working on planed surfaces, so as to admit of a horizontal movement during expansion and contraction under changes of atmospheric temperature, as well as of a circular vertical movement to compensate the deflection arising from loads on the girder. The maximum horizontal movement due to a high natural temperature is about 1½ inch, the greatest actual movement taking place when the

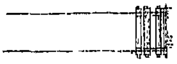
PLATE XXXIV.



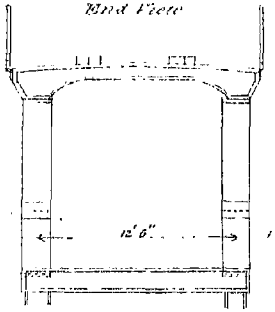
Note... Th

Cross Section.





End View



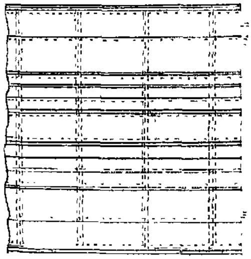
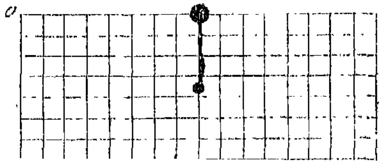


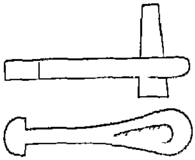
Diagram showing deflection of No. 5 Span of Tonse Bridge taken during the passage of a train weighing 100 Tons, March 31st 1864.



nights are cold; the girders expand in the hot weather to the full extent, and their length remains then unaltered till a decided change of weather sets in. Under a June sun the iron-work becomes heated to a degree that renders it difficult to keep the hand long upon it.

The ironwork of the westernmost, or of No. 7 span, was the first commenced. The parts had been carried into the river bed and laid under the staging during the erection of the stage, and on 24th March, 1862, the first portion was sent up for erection. This was one of the central outside plates of the lower member, the whole of which was laid down as fast as the materials could be got up. The tension links were laid down to the camber and proper line, and temporarily connected by pins or "drifts" passed loosely through the holes; on removing these, the bolts were substituted. These bolts are most important parts of the bridge, and ought to fit with the greatest accuracy. To prevent any bending of the bolts or damage to the screwed ends, they were driven in with 10 lb. copper headed hammers, or with ordinary sledges, with a lead packing next to the bolts. These bolts are of the best Bowling-bridge iron, and very great care had been bestowed on their turning and finishing.

The lower member being completed, the central diaphrams were next got on end and secured in their places by colters. Of these little implements, represented in sketch, several thousand were made to secure the parts of the bridge loosely together during erection, bolts being employed for the same purpose where greater accuracy was requisite. The centre "top box" was next sent up and temporarily secured, the others were then added, resting on the cross beams of the stage; the vertical boxes or end standards were last got into place.



The framework or outline of the girder being thus completed, the lattice bars were got in and rivetted to the upper and lower members, the top boxes being simultaneously rivetted together with the iron beams carrying the roadway overhead.

A few of the iron joists of the lower roadway were coltered on to keep the girder steady, and a few colters put into the intersections of the lattice, one row of which on each side was also rivetted up. The girder was then ready for "launching" or lowering down on its bearings. This operation commonly took about 20 minutes, men being stationed at each pair of wedges, both above and below, to drive them back with sledge hammers. The levels of about six points had been previously observed with a spirit level, placed on one of the piers, and these were again read off when the whole of the wedges were clear of the girder, and the deflection in launching noted. The amount of this deflection or descent of the girder is in a great degree a test of the workmanship displayed in the manufacture of the parts, and more especially in the erection and rivetting up. It amounted on an average of the spans to 1⅝-inch, its minimum was ⅝-inch, and maximum 2¼ inches. The amount of camber, or upward curve, given to the spans, was from 3 to 5 inches, from which the descent in launching was a deduction. This remaining cambre was reduced further to one inch at the rail surface by adjusting it in the timber longitudinals of the road.

The girder being lowered upon its bearings, the stage was next pulled down, and re-erected for another span; three sets of staging, or a complete set for each of three spans, being used in erecting the seven spans of the bridge.

At the commencement of the rains in 1863, instead of pulling down the travelling crane, it was placed on a low truck, running on a line of rails temporarily laid on the top of the spans, and blocked with timber so as to steady it. The stage was removed from beneath it, leaving the side frames suspended outside the girder. When required to be removed to another span, as there were no stages to carry it, it was transferred upon the truck along the girders already completed to the stage, which was ready to receive its wheels, for the erection of another span. The crane weighed 7 tons, and it was a considerable saving of time and expense to avoid taking it down and erecting it on the top of the new stage when the rains were over.

This crane was calculated to lift about 2 tons, and with it all the heavier parts of the girders were erected, except the bed-plates and end standards, which were sent up by the large derrick before-mentioned. The lighter parts were sent up "by the run" by means of tackles hooked on the work where convenient; besides which a considerable number of the parts were carried up a slope of bamboos erected to give access to the spans for the workpeople. Besides the above tackle, a small derrick standing in the lower roadway was found very convenient.

Ten or twelve sets of rivetters were employed in rivetting-up each span; each set consisting of four smiths. Portable forges were sent out from England for this work, but were speedily abandoned for the common native forge, in which a small plate of iron for the fire, and a hand-bellows is all the apparatus necessary, and which constitute a forge far more convenient to natives, than those on the English plan. For the *workshops*, however, the English forge is almost essential.

The most important of the other tools were screw jacks of from 5 to 12 tons purchase, and powerful screw clamps for closing the bars of the lattice solidly together while rivetting.

The rivetters had been well trained at the Soane bridge, and were thoroughly accustomed to the work; the English rivetters being mainly employed in superintendence.

After the girders had been launched, they were completed during the rains. The upper floor is covered with iron plates, the lower with a double layer of diagonally laid sál planking caulked at the joints, and 5 inches in total thickness.

In the case of the last two spans erected, the stages and pier were carried up simultaneously, and a considerable portion of the girder, No. 6, was built on the stage before the pier had reached the level of the bottom of it, so that no time was lost in the erection of the pier and girders.

The average time of erecting a span from the laying down of the first plate to the "launching" was 28 days.

The bridge was ready for testing by February 22nd, 1864, when the first locomotive passed slowly over the bridge, and shortly afterwards returned at speed.

The bridge was tested next day by running a train weighing 200 tons over it at full speed, and observing the deflection produced by repeated passages. The maximum deflection noted was $\frac{9}{16}$-inch, and the side vibration was but $\frac{2}{16}$-inch, or almost nil. The girders sprung up to their original shape immediately after the train had passed them. The deflection was recorded by a pencil fixed to the lower part of one of the spans which was pressed by the hand against a graduated paper fixed on a firm basis independent of the span. The amount of descent of the pencil was checked by observing a point on the girder with a spirit level placed on the adjoining pier.

A copy of one of these papers is appended, showing the diagram resulting from the passage of a train weighing about 100 tons at 25 miles per hour.

The rails were fixed in the ordinary chairs, spiked to beams of fir or sál timber, bolted to the cross bearers of the span with four $\frac{5}{8}$-inch bolts at every intersection, and halved, but not secured together at the ends, play being allowed in the halving for the expansion of the girder. The rails were also cut to a half-lap joint at the ends, which was secured by the ordinary fish plates, having the bolt-holes slotted to allow of the rail and bolts advancing and retiring with changes of temperature.

When the fish plate bolts were screwed tight, the movement, which took place about an hour after sunset, was attended with rather a loud cracking sound, arising from the friction of the plates and rail, and the former became distinctly *magnetic* from the effect of friction.

There are two small spans formed of box girders of 24 feet in length, giving access to the lower roadway at the ends of the bridge, and covered with iron plates in continuation of those on the main spans. These box girders rest on expansion rollers sunk in the stones which carry them.

The lattice girder appears peculiarly adapted for bridges over Indian rivers and for railway work in general, from the multiplication of its parts, which in a great measure obviates the effects of bad workmanship in erecting; an important thing, as rivetting done by natives of India is never so good as that done by Englishmen. A defective portion, moreover, can be removed and another inserted without detriment to the structure, which has the further advantage of being composed mainly of bars and not plates, which must be an element of durability. The parts of a lattice girder moreover are light and of manageable size, a great consideration in India.

147. IRON ARCHED BRIDGES have been growing out of favor during the last few years, which is certainly to be regretted, considering the many beautiful specimens that have been erected, and the very ugly plate Girders that have in many instances usurped their place. Where beauty is studied as well as economy, the arch will hardly be displaced by any straight combination of forms known to the Engineer at present.

The employment of Wrought-iron for arches has been chiefly confined to bridges of the Suspension and Bow-string classes. The best examples of the arch proper are of Cast-iron. In the first instances the Metal Arch was supposed to come under the same conditions of equilibrium as an arch of Masonry; but where the weight of the rolling load bears so large a proportion to the weight of the structure, as is the case in all railway bridges, and seeing that the bearing surfaces of the segments of the arch are rigidly restrained by bolts, this theory is inadmissible, and is now generally abandoned.

The Metal Arch appears to combine in itself the properties both of the web and of the horizontal flanges in the Plate and Lattice girders. Thus at the summit of the arch there is a horizontal strain exactly equal to that which would exist in a straight girder of equal span and load, having a depth equal to the versine; and the same formula applies, $S = \frac{Wl}{8d}$ for the horizontal strain at the crown of the arch.

As we progress from the crown of the arch to the abutment plate, the rib assumes more and more the offices of the web in the plate or lattice girder, and if at the abutment a tangent to the arch be vertical, the rib at that place assumes completely the conditions of the standard or strut at the end of a straight girder.

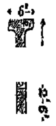
Mathematically, it is found that an iron arch having merely a fixed load to sustain, should be of a parabolic form. With a rolling load, supposing the arch itself to be devoid of weight, the curve should be an ellipse. In practice, where of course the weight of the arch *has* to be taken into consideration, the curve should be between the two, inclining to one or the other according as the fixed or rolling load preponderates.

An ordinary cast-iron arched rib consists of three pieces, 1st, the Arched rib itself, which is made in several castings united by wrought-iron tie-bolts; 2nd, the Girder which carries the platform, and which comes under the conditions of an ordinary continuous girder; 3rd, the Spandrils which are evidently a modification of the lattice girder. A proper number of these ribs having been put up they are braced together and the platform placed on the top. The section usually adopted for arched ribs whether of cast or wrought-iron is the simplest of the forms employed for plate girders, the **I** section.

148. *Strength.*—Let us suppose that a cast-iron arch is required to carry a double line of rails over a span of 100 feet. Let the weight of the structure be 2·5 tons per lineal foot, that of the rolling load 2 tons, let the versine be 8 feet 6 inches. The rib is supposed to be braced so as only to be subject to direct strains.

Then as said above, the strain at the crown will be $S = \frac{W l}{8 d}$ $= \frac{(4·5 \times 100) \times 100}{68} = 662$ tons nearly, and taking 5 tons per square inch as the working resistance of cast-iron to compression, the total sectional area at crown will be $\frac{662}{5} = 132·4$ square inches. If there are 3 ribs, the sectional area of each would be made 50 square inches to allow for defects in casting.

This area may be provided by using such a section as the one shown.



The compressive strain on the transverse section at the abutments will be

$$C = \sqrt{\frac{W^2}{4}}$$

$= \sqrt{(662)^2 + (4 \cdot 5 \times 50)^2} = 695$ tons nearly, requiring a sectional area of 139 square inches. It would be advisable, therefore, to make the ribs 2 feet 9 inches deep at this place, the other dimensions being the same.

If the ribs were of wrought-iron, the compressive strain would be taken at 4 tons, and dimensions somewhat greater than the above would be given.

The other details of arched ribs do not require description.

149. The following is a description of the Iron Bridge over the Goomtee at Lucknow, of which an engraving is given in the present volume:—

> This graceful structure consists of three cast-iron arches supported on piers and abutments of brick masonry, the centre arch having a span of 90 and a rise of 7 feet, while the two side arches have spans of 80 feet, and a rise of 6 feet. The iron work was received from England in 1798, during the reign of Nawab Saadut Ali Khan, only twenty years after the erection of the first iron bridge in England, General Martin, who was then living at Lucknow, having it is supposed suggested the idea to the Nawab.
>
> The bridge was designed by Rennie, being very similar to one erected by that famous Engineer over the Witham, at Boston, in Lincolnshire. The iron work remained unused at Lucknow *more than forty years*, when the bridge was at length erected by Col. Fraser, Bengal Engineers, between the years 1841-44; the cost of the masonry and erection having been Rs. 1,80,000; the cost of the iron work is not known.
>
> The foundations are sunk on wells in the usual way. The width of roadway is 30 feet, and its height above water-mark at the centre is 35 feet.

150. If we unite the ends of the arch by tie-bars, we do away with the *horizontal thrust against the abutments; the tension on the tie-bar is then* equal to the horizontal strain at the crown $= \frac{W\, l}{8\, d}$. In *Bow-string* girders the roadway is usually suspended from the arch by standards, the lower extremities of which are retained at their proper distances by pins passing through them and the tie-bars. The arch and its tie are braced to resist the vibration of the roadway. The finest example of this form of bridge is the High Level Bridge at Newcastle-on-Tyne.

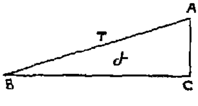
The mode for calculating the strains on the several parts has already been given in the last chapter.

The principles involved in the construction of *Suspension Bridges* are similar to those of the arch, as the curve of the chain may be considered an inverted arch, the strains being however, tensile, and not compressive. If the chain were prefectly flexible and had only its own weight to sustain, the curve taken by it would be that known as a *Catenary*. Practically, it is convenient, and sufficiently accurate to treat it as a parabola.

In suspension bridges, the roadway is suspended by vertical rods to chains of flat iron links, or to iron-wire ropes, which hang from cradles or saddles carried by masonry or iron piers, and are continued on the opposite side to what are called the anchoring-wells. The chains in such cases have permanently to support an effort compounded of, 1, their own weight; 2, of the weight of the suspension-rods, which varies with the lengths of the latter; and 3, of the weight of the roadway, which may be considered to be uniform in the length of the span. But in addition to this permanent effort, it is necessary to take into account the rolling load, the action of wind upon the whole structure, and, as in the case of all iron bridges, the effect of variations in the temperature upon the various parts of the work. Local circumstances, also, may render it necessary to modify the general system of suspension bridges; for at times it may be desirable to dispense with the piers and back chains, whilst in others it may be necessary to introduce a series of spans; in the latter cases, the chains may either be attached to the respective piers, or they may be carried over a series of saddles.

According to Navier (whose work, "Mémoire sur les Ponts Suspendus," Paris, 1830, is still the text book upon this subject), the formulæ which may be considered to represent the maximum tension in the direction of the arcs, and the horizontal tension at the top of the piers are $T = \frac{W}{4} \sqrt{\left(\frac{l^2}{4d^2} + 1\right)}$; and $S = \frac{Wl}{8d}$; in which W is the total maximum load upon the arc; l the span; and d the versed sine.

Also, if any bar be inclined at an angle α to horizon, and if AC represent the weight W^1 supported by that bar, then the tension $= \frac{W^1}{\sin \alpha}$, and from the properties of the parabola we may find the length of the suspending rods and chain.



The horizontal strain at the centre equals, as before, $S = \frac{Wl}{8d}$, and the tension at any point $= \sqrt{S^2 + (wy)^2}$, y being horizontal distance of the point from centre of span, and w as before $= \frac{W}{l} =$ load per lineal foot. Supposing it were required to construct suspension chains subject to a strain of 1,000 tons at the centre, then the effective area would be $\frac{1000}{5} = 200$ square inches. If there be 2 chains, each must be 100, which could be supplied by 10 bars, 1-inch

thick and 10 inches deep, alternated by 9 bars 1⅜ thick and 10 inches deep, but the ends of the bars must be made wider to give room for the connecting pin, and would be as in the margin.

From the above formulæ it appears that the greater the versed sine the less strain is there upon the piers, or upon the chains themselves; but, at the same time, the length of the chain is necessarily increased, and the horizontal vibrations of the whole system are also rendered more dangerous, whilst the transverse vibrations are likewise increased. For these reasons, the ratio of the versed sine to the span of suspension bridges is usually made to vary between the maximum of 1·7, to the minimum of 1·25; and in the Fribourg Bridge, the largest span hitherto attempted, the ratio is 1·14. The latter ratio is the one most commonly adopted. In all cases, and whatever be the material of the chains, the suspension rods are placed at equal distances horizontally.

One of the most important parts of a suspension-bridge is the anchoring of the end of the chain, so as to interfere as little as possible with the contraction and expansion of its metal, and yet to resist the tension. Great precautions require to be taken, especially in the tying-down wells, to protect the chains from oxidation; and it may be interesting to add, that some of the worst accidents to suspension bridges have arisen from the destruction of the sunk part of the back chains, precisely from this cause. This was the case with the bridge at Angers, which fell in consequence of the rusting of the wire-ropes in the wells; and so much are the said wire-ropes exposed to this particular danger, that it would appear to be desirable to exclude them entirely from that part of the work. In the open air, or in positions where they can be easily examined, however, iron-wire ropes present many advantages over the solid bar-iron chains or suspension-rods.

The "Dredge's Suspension bridges," which were very favorably received in England a few years since, have been even more unfortunate than the other modifications of this style of bridge. They were principally remarkable for the attempted application in them of the theoretical principle that the strength, and consequently the weight, of the chain in any part of its length should diminish in proportion to the strain likely to be thrown upon it, and also for the peculiar inclined position of the suspension rods. Such a system, however, is deficient in its powers of resistance to either horizontal or transverse waves, precisely at the point where their action is the greatest; and the consequence has been that the platforms have been obliged in many cases to be supported by an intermediate framing.

It must be observed that, whatever be the description of chain employed in a suspension bridge, the greatest danger to which that class of structures is exposed arises from regular impulses repeated at isochronous intervals. Occasionally the gusts of wind in storms occur thus; and the regular cadence of a body of troops passing over a suspension bridge will also excite a vibration of a very dangerous character. In the case of the Pesth Bridge, however, the dimensions given to the various parts of the work have been sufficient to enable that structure to resist even the passage of troops in large bodies, in the hurry of a fierce fight.

The French government do not allow greater permanent weights than those quoted below to be applied to the respective materials named in the table; and they require that the dimensions of the various parts of the works should be calculated so as to present the sectional areas corresponding with the safety loads thus indicated.

Chain cables, safe load, per inch superficial,	...	17,073 lbs.
Iron wire cables, safe load, per inch superficial,	...	25,610 „
Vat hoop iron cables, safe load, per inch superficial,	...	19,913 „

Owing to the great danger from vibration, suspension bridges are ill adapted for railways. But for roadways they are economical and convenient for large spans, being light and independent of the nature of the obstacle they have to surmount.

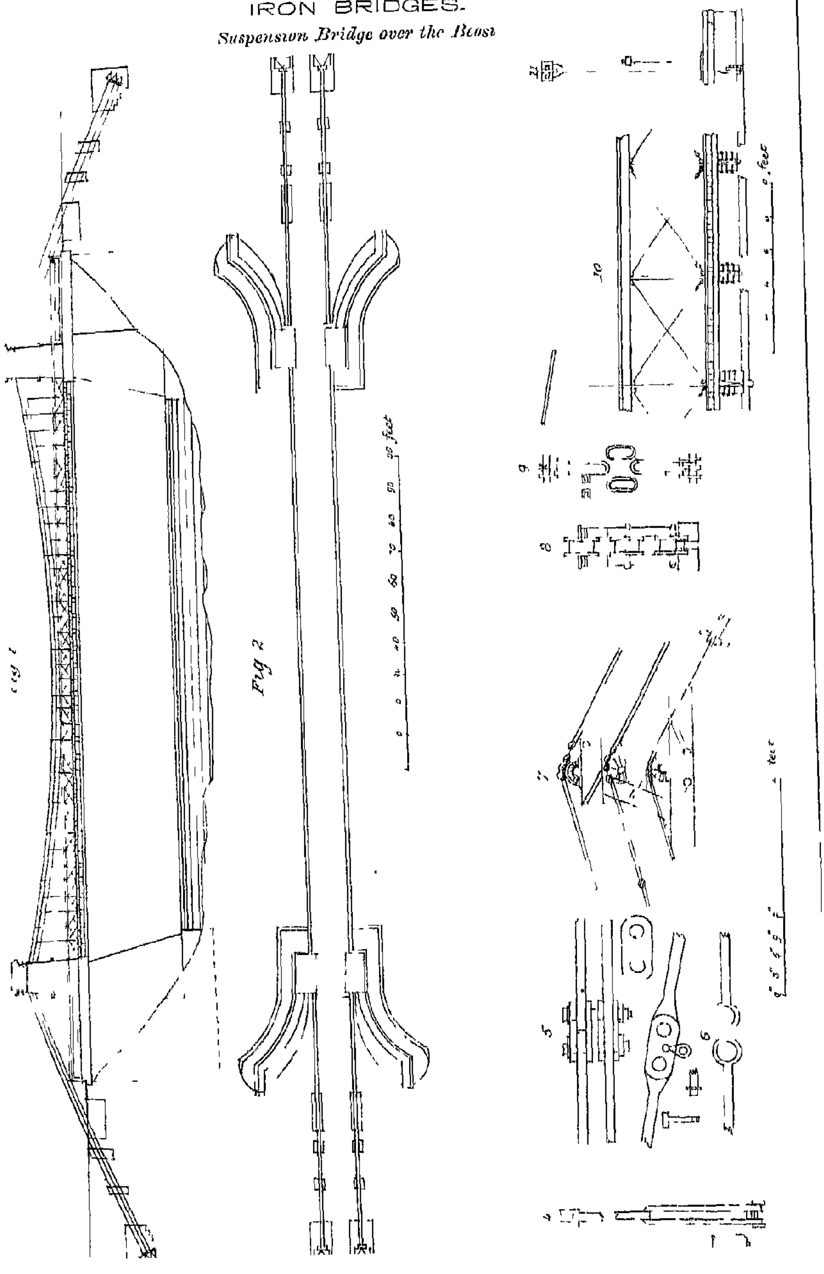
Of late, however, successful attempts have been made to adapt Suspension Bridges for Railways by employing various means to ensure proper rigidity. In the Niagara Bridge, this has been effected by under-bracing, but this is not always practicable. It is better to make the parapet into a trellis or lattice girder, and carry it through the suspension towers. By making this girder strong enough to carry its own weight and that of the platform, independently of the chains, the whole of the latter is available for supporting the rolling load, and great stiffness is imparted to the structure. The danger of this arrangement arises from the possible unequal contraction and expansion of the chains and girders, by which the whole load might be thrown upon either without assistance from the other.

A bridge of this kind has lately been designed by Lieut.-Colonel Taylor, C.B., R.E., for crossing the Indus at Attock.

151. The following is a description of the Suspension Bridge over the

IRON BRIDGES.

Suspension Bridge over the Beasi



river Beosi, near Saugur, in Central India, which is interesting as having been entirely made up in this country, some 30 years ago, and erected without skilled workmen:—

The bridge is 200 feet in span between the points of suspension.

The piers, resting on the solid rock, 6 feet under the low level of the river, are 42 feet high to the roadway; being elevated two feet above the ordinary surface of the country; they have a base of 32 feet by 22½, decreasing upwards in front 1 in 5, and on the sides 1 in 8 feet, which gives on the road a superficies of 21 by 14 feet for each pier. On the sides are wing walls or abutments, running back into the bank 26 feet.

The pillars, or rather arches, of suspension, have a base of 21 by 12 feet, admitting a roadway of 9 feet broad. The arches are 15 feet high, and are faced with accurately wrought stone. The points of suspension are elevated 22 feet 4½ inches from the road; the pillars have a total height of 33 feet, and the whole masonry from the rock, 68 feet The piers and abutments contain 82,188 cubic feet of masonry; the arched standards and bridge parapets, 8,900; in all 91,388 cubic feet.

The platform measures 200 feet in length by 12 feet broad, and is calculated to weigh, with the chains, 52¾ tons. Supposing the bridge loaded with 69 lbs. per superficial foot, all over the platform, the whole weight would be 120 tons, whence it is calculated that the tension to be sustained at each point of suspension would be 85 632 tons.

The suspending chains are 12 in number, arranged in pairs, three pairs on either side, 2 feet above one another. They pass over rollers one foot in diameter, and are securely moored in masonry 16 feet below the surface of the road. The back chains are 101 feet long, rising at an angle of 27 degrees. The angle of the catenarian at the roller is 16° with the horizon, the versed sine at the centre of the curve is 14 feet 8 inches.

The 12 main chains are of round bar iron 1½-inch diameter, bolted together in pairs. They are from 15 to 15·5 feet long, and so arranged that the vertical rods may fall from the joints of each chain alternately in parallel lines 5 feet apart the descending chains are square bars measuring 1¼-inch on the side; their lower ends pass through 24 conically wrought stones, below which they are capped and keyed. (*Figs.* 1 and 2)

The connecting links of the chains, and indeed all the bolt holes in the bars and the drops, are bored out of the solid iron, and broached to fit the bolts accurately. (*Figs.* 5 and 6.) None were punched at the forge. The bolts are 1½-inch in diameter, and are secured by rings, or washers and keys. Two adjusting links with iron wedges are fitted to each chain, close to the masonry landward, to regulate its curve and dip. (*Figs.* 7 and 9.)

"The iron rollers, 12 in number, weigh about one cwt. each. They are not solid, but are composed each of about 28 separate pieces of wrought-iron, viz., a centre tube or box for the axle over which thick rings are driven; and an exterior drum between which and the inner ringed tube, flattened bars, as spokes, are driven. The centres were broached out clean and true, and cylindrical axles 3·1 inch in diameter were turned to fit, the ends of these axles rest on broad thick iron bearings, mounted on very strong and solid frames of timber well bolted, clamped, and blocked together, covered with pitch cement, and secured in the masonry of the pillars. (*Figs.* 7, 8.)

Platform.—"From the short links set between the centre plates of the shackles (of the main chains) are suspended alternately from each tier, 74 vertical round rods one inch in diameter, connected to a short link (*Fig.* 6) by a 1-inch round bolt passing through it and the socket at the upper end of the bar; at their lower ends the rods have eyes, through which doubled loops of iron pass (*Figs.* 3, 4,) for sustaining the flat bars or girders, set on their edges and proceeding from one end to the other on both sides of the bridge.

"The flat bars, 4 inches broad by ¾-inch thick, and in lengths of 15 feet, are joined together at their ends by nicely turned bolts passing through bored holes 2 inches in diameter; they are adjusted in their height by double wedges, resting on holders that connect the sides of the loops together. The girders are also adjustable in their lengths, the bars that enter the masonry have their ends made broader than the rest of the bars in which are long openings 2 inches broad to receive wedges (*Figs.* 10 and 11.)

"Eight timbers in an upright position are set in the masonry of the pillars, having upright grooves or spaces cut through them, and faced with thick plates of iron; through two of these beams each end bar passes, and may be wedged on either side of the timber towards the land as occasion may require; thus is the whole length of girder drawn more or less to either end of the bridge, and also rendered exceedingly tight and steady. The grooves in the timbers towards the river, being about 4 inches longer than the breadth of the bars, permit them to adapt themselves to their proper directions when drawn lengthwise by the wedges acting against the landward beams; by these means the bars have sufficient play to adapt themselves to the motion of the platform, and all jerks at the pillars are obviated.

"Thirty-seven double joists 12 feet long are (having their ends notched below for the purpose) laid on the girders: their centres 5 feet apart correspond exactly with the vertical rods that pass through them; the joists are composed each of two cheeks a foot in depth and 3 inches thick, separated at intervals by four blocks of wood of the same height and thickness; all firmly put together with bolts, screws, and nuts: two cleats are nailed to each end of the joists on their under sides, whose ends fit flat against the girder and keep all steady.

"Planks 16 feet in length running longitudinally, each plank stretching over three spaces, and regularly disposed as to their joints, are spiked down on the joists; in a direction across these, and upon them other planks are spiked down, their lengths being the same as the breadth of the platform. The planks are all imbedded in a composition of resin boiled in linseed oil, which in laying on is mixed with ashes. The lower planks are 3, and the upper ones 2½, inches thick; they are only 6 inches broad to prevent warping, and have two strong square-headed spikes passing through them near their edges, at every crossing of the upper over the lower planks; their points are clinched below the platform, to accomplish which, 16,370 spikes, weighing a ton and a half, were used; thus the platform has been rendered extremely strong and firm.

"The better to secure the sides of the platform and the ends of the timbers from the weather, a cornice or moulding of wood is nailed along the outside.

"The hand-rail is trussed, and consists of iron pillars or stanchions; diagonal braces of iron; and a stout wooden rail running from end to end of the platform; the whole put together with screws and nuts, and adjusting screws for setting up or tightening the diagonal braces whenever required. (*Fig.* 10.)

"The rise in the platform is (as before stated) 9 inches, but the curve of the hand-rail is only 3 inches, to effect which the stanchions that support the rail are of varying lengths. The rail being 4 feet 6 inches above the platform at its connection with the masonry, but only 4 feet in the centre of the bridge."

The following are the weights of the chains, rods and materials of the platform :—

	Iron. Tons.	*Wood. Tons.*	*Tons.*
6 double main chains, joints and bolts, ...	8·5	...	...
74 vertical rods, with joints, bolts, &c., . . .	1·385	...	...
Flat bars and bolts, ...	1·726	...	...
37 double joists, blocks, cleats, &c., ...	...	6·190	...
Bolts, nuts, screws, stanchion plates, flat rings, &c., from beams, ...	0·383	...	...
Planking 1,124 cubic feet, sál wood, ...	...	27·000	...
Iron spikes, 16,370, for planking, ...	1·467	...	...
Iron railing trussed, screws, nuts, &c., ...	1·314	...	...
Wood for the hand-rail, 52 cubic feet, ...	...	1·479	...
376 feet of cornice to the platform, ...	...	1·531	...
	14·775	36·200	50·975
Composition of resin and oil, ...	...	...	1·745
Total weight hung between the pillars, ...	...	...	52·720

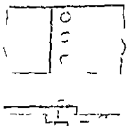
152. The *Bolts*, *Rivets*, *Keys*, &c., used in connecting the various joints employed in Iron Bridges, require consideration as to their proper diameter, as also the proper form of joint in the several cases. It is too long a subject to be gone into minutely here, but one or two leading points may be noticed.

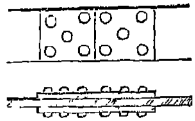
If two plates of iron are rivetted together and subjected to a compressive strain, their strength is practically not reduced by the rivet holes, provided that the latter are completely filled by the rivets.

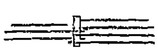
If they are subject to a *tensile* strain, the nett or effective area of the joined plates will be found by deducting the area of rivet holes in any section of the plate from the total area of such section.

If S be the strain to which the joint will be subject, n the number of rivets, d the diameter of one, then $d = \sqrt{\frac{\quad}{3\cdot1416n}}$

If b be the breadth of the covering plate, t the thickness of the plates, then S the strain $= 5bt - 5dtn = 5t\,(b - nd)$; when substituting the above value of d we can get the requisite breadth of plate b.







From the above calculations it will be found that a single rivetted lap joint could never be made as strong as the entire plate, but that in all cases cover plates of sufficient size with a sufficient number of rivets must be used, according to the strain on the joint, and according to the formula given above. These cover plates should be arranged so as to break joint at the top and bottom of the girder. In the case of a suspension bridge, $d = \sqrt{\frac{S}{3{\cdot}1416n}}$ as before, n being in this case the number of sections at which the pin must be divided before the joint can fail, *i. e.*, = twice the least number of links.

153. *Iron piers.*—Hitherto we have supposed the superstructure of our Iron Bridges to rest upon Masonry piers, but to complete the subject, something may be said of Iron Piers which have been much used of late, and which would seem to be peculiarly adapted in many cases to Indian requirements.

Iron piers consist of a series of hollow iron piles sunk by different methods into the bed of the river to be crossed, on the top of which cross girders are fixed to carry the longitudinal girders forming the roadway. These piles may be of Cast or Wrought iron.

The Cast-iron piles are hollow cylinders, from 6 to 10 feet in diameter, being in fact iron wells, which are sunk either like masonry wells or by pneumatic pressure. These cylinders are made in lengths, having flanges at their extremities, by which they are joined to the next lengths by wrought-iron bolts. On reaching a firm foundation below they can be filled with concrete. Two or three are generally used for a pier; they have been employed on the Eastern Bengal Railway, and are about to be used on the Umritsur and Dehli Line, for crossing the large rivers, the superstructure, consisting of plate girders of 100 feet span.

Wrought-iron screw piles are of smaller diameter, about $2\frac{1}{2}$ feet, made also in lengths, and having a cast-iron screw at the end by which they are worked into the bed from a stage above. If the pier is of any height, three of these piles may be fixed vertically, and two others on the outside obliquely, to act as stays; the whole being firmly braced together at intervals by iron ties. They have been largely used on the Bombay and Baroda line, where they support girders on Warren's principal. The cost of these bridges, complete, for a double line of rails appears to have varied from £20 to £40 per lineal foot on an average, actually erected; the spans being 60 feet and the total heights of piers ranging from 30 to 90 feet.

SECTION VIII.—ROADS.

CHAPTER XXXIV.

TEMPORARY ROADS.

154. ROADS differ much in their nature according to the purposes to which they are applied and the amount of labor that has been expended upon them.

The first idea of a road, is a path or track on which a foot passenger can travel. In the American forests the trees are blazed or marked to show the direction. On the prairies men travel by compass or by the stars; or by watching their own shadows, or noting the direction of the wind. Successive travellers following the same route, will tread down a forest path, which is the first step towards road-making. On such a road, rivers will be crossed by swimming or wading, or by rafts; or felled trees might be used on very narrow streams; while ranges of hills would be passed by following the beds of mountain torrents.

As intercourse increases, various animals are used as beasts of burden. Pack horses were employed in England down to a very late period; camels, horses, mules, asses and bullocks, are used all over the East, while even sheep bring tea and take salt over the Thibet passes. And the employment of any of these animals necessitates the improvement of the roads; the foot-paths are widened, the jungle is cleared, rude bridges of logs are formed or rafts made of wood, of empty vessels, or of inflated skins.

But as animal power is always more economically employed in draught than in carriage, carts are soon built for conveying goods and passengers. Hence attention is requisite to Gradients; the road must be raised clear of inundation from rain or river, so that the water may run of easily; permanent bridges are provided over the water-courses, and finally the surface is metalled to diminish friction and the loss of power of animals, and wear and tear of vehicles. These improvements would however be preceded by new straight lines being marked out to save labor, distance and cost, both of construction and subsequent repair.

155. It would be out of place here to dilate on the importance of roads. Suffice it to say, that that importance is now so well recognised in India, that numerous lines are under construction in various parts of the country, and are only the prelude to very many others. All of these are not of equal importance and we may begin with what are called *Fairweather Roads*, which as their name denotes, are temporary expedients, and often the useful and economical precursors of a system of permanent roads in a new province; the latter requiring much time, labor, and skill to be bestowed on them, while the former can often be opened out at a very cheap rate. But this should always be done with an eye to future improvement, so that labor may not be thrown away, and that progress however slow may be in the right direction.

Supposing such a road to require making from one town or settlement to another in a wild unmapped country, if a traverse were run by compass and chain between the two places, and plotted on paper, the magnetic bearing of the one place from the other would be ascertained and a straight line could be run between the two by means of the compass. If two flags are set up in the proper direction at some distance apart, then, by means of a third flag brought into line with the two former, a straight line could be run for many miles with a very slight deviation from accuracy. Where a compass is not available, a fire lighted at one place may by its smoke enable its direction to be seen from the other.

This line so run, and marked by a trench cut in the ground will often be a practicable line for the road in a new country; if not, it will, at any rate, be a valuable guiding line towards which all deviations caused by various obstacles should return; the line so marked out will be cleared of jungle for a width of 10, 20, or 30 feet; a ditch cut on either side to serve as a drain, and the earth excavated thrown in the centre of the road to assist the rain water to run into the ditches. Inequalities of surface can then be levelled as far as possible. Small streams may be crossed by temporary bridges, if wood is available, if not, their banks must be cut down, if necessary, to a gentle slope, so as to enable carts to pass when the stream is dry or nearly so, and such slopes as well as the bottom of the stream may be paved if material is available.

Of course it is useless metalling such a road until it is raised clear of inundation; but after the rainy season, repairs may be made as far as possible, and, in a dry country like Upper India, such a road would be open for wheeled traffic for nine months out of the twelve. There are many such lines in India, and bad as they are, they are a great improvement on the old native tracks, which were narrow, crooked, and scarcely ever repaired.

The cost of such a road will vary from 100 to 500 rupees a mile, according to the scarcity of labor, the difficulty of the ground, or the extent to which the road track is improved.

There are several temporary expedients which may be used as a substitute for metalling; thus, stable litter, when available, or even grass strewed on the sandy or dusty surface, will greatly improve it. A road passing through the deep sandy bed of a river may be much improved by cutting down through the loose sand to the moist and firmer stratum; on this should be laid a flooring of fascines, 6 inches in diameter, made of *jhow*, or of the strong grass which generally grows upon the banks of rivers in this country, and over all, from 1 foot to 1 foot 6 inches of earth well beaten down; such a road would hardly last more than one season, but it would not cost much, and its advantage would be very great in saving draught cattle, the toil of struggling through heavy sand, often worse than an additional day's journey. This plan has been pursued with great success at several of the large rivers, such as the Sutlej. It is also applicable to the crossing of a swamp or bog, of which more will be said further on.

156. The following is a detail of a temporary road of this kind made over the dry bed of the Chenab River in the Punjab.

The total length for the roadway across the Chenab measures 10,600 running feet, of which 1,350 feet consist of a metalled road laid down last year, and now in good order; 3,500 feet resting on firm soil, extending from the road embankment to within 1,000 feet of south side of river, and the remaining 5,800 running feet extend across entire sand.

Specification.—The roadway to consist of one layer of grass fascines, each fascine to be 24 feet long, 6 inches in diameter, and tightly bound with grass, to be packed closely together and covered with 6 inches of clay. On the surface of the clay and to prevent its cutting into grooves a very thin layer of loose grass will be constantly maintained. An inch of clay will be first laid down on the sand, all hollows to be filled in and low points to be somewhat raised, that the foundation may not suffer from the lodgment of water.

In other places the finished road to be 1 or 2 inches above the sand

The total cost was Rs. 1,901 ; being Rs. 1-1 per 100 superficial feet, or Rs. 33 per 100 lineal feet of roadway. The work has answered well, effecting a considerable saving in the tractive force required through the heavy sand. Though such a road will only last one season, its utility and economy will always justify such a construction being employed in all lines of heavy traffic. Wherever the fascines can be pegged down, the improvement will be great.

157. Whatever improvements are made in such roads should be directed towards the most formidable obstacles at first; this is, indeed, self-evident, (the strength of a road, as of a beam being only that of its weakest part,) but it is not always easy to determine what *are* the most formidable obstacles, nor whether it will be more economical to lay out a given sum in raising a portion of embankment, cutting down a hill, improving the surface, or building a bridge. Much of course will depend on the peculiar circumstances of each case, and some of the considerations by which the judgment should be guided will be treated of farther on.

A common mistake in India is to make kucha roads too wide. If the traffic is only sufficient to demand a kucha road, it will be better to make that only 20 feet wide, and to keep it in thorough repair, than to have a width of 40 feet cut up by wheel ruts, or half covered with grass.

Again, it is not uncommon to find a kucha road good in other respects with a short length of it perhaps almost impassable, either from having to go through sandy or swampy soil, or over a steep hill at that part. In such a case it is evident that much money may be justifiably expended in bringing the short difficult portion up to the same standard as the rest.

CHAPTER XXXV.

GRADIENTS AND CROSS SECTION.

158. WE come now to the question of *Permanent Roads*, which we shall consider under the following heads. 1st, Direction; 2nd, Gradients; 3rd, Cross Section; 4th, Metalling; 5th, Survey, Design and Estimate; 6th, Construction; 7th, Maintenance and Repairs.

Direction.—Other things being equal, a road should be straight, as being the shortest distance between the two points to be connected. Any unnecessary excess of length involving a constant three-fold waste; 1st, of the interest of the capital expended in making the unnecessary portion; 2nd, of the expense of repairing it; 3rd, of the time and labor employed in travelling on it. On the other hand as the great object of a road is to accomodate the traffic of the country, so its direction must primarily be regulated with a view to such traffic, *i. e.*, it should pass through or close to as many towns and villages, as possible; while the object of the Engineer must be to overcome by skilful means the various natural obstacles interposed along its course.

But straightness is of less consequence than easy gradients, and must always be sacrificed to them, and this is one of the most important principles to be observed in designing a road.

A *straight* road over an uneven and hilly country may, at first view, when merely seen upon the map, be pronounced to be a *bad* road: for the straightness must have been obtained either by submitting to steep slopes in ascending the hills and descending into the valleys, or these natural obstacles must have been overcome by incurring a great and unnecessary expense in making deep cuttings and fillings.

A good road should wind around these hills instead of running over them, and this it may often do without at all increasing its length. For if a hemisphere (such as half a bullet) be placed so as to rest upon its plane base, the halves of great circles which join two opposite points of this base are all equal, whether they pass horizontally or vertically; or let an egg be laid upon a table, and it will be seen that *if a level line be traced upon it* from one end to the other, it will be no longer than the line traced between the same points, but passing over the top. Precisely so may the curving road *around* a hill be often no longer than the straight one *over* it.

But even if the level and curved road were very much longer than the straight and steep one, it would almost always be better to adopt the former; for on it a horse could safely and rapidly draw his full load, while on the other he could carry only part of his load up the hill, and must diminish his speed in descending it. As a general rule, the horizontal length of a road may be advantageously increased, to avoid an ascent, by at least twenty times the perpendicular height, which is to be thus saved; that is, to escape a hill a hundred feet high, it would be proper for the road to make such a circuit as would increase its length two thousand feet.

Deviations from the direct line should also be make in order to carry the road over high well-drained ground, where few embankments and bridges will be required—or to avoid heavy cuttings—or to have materials for the road surface close at hand, by which money will be saved both in first cost and periodical repairs. Minor deviations will have to be made in order to cross rivers at the places best suited for the construction of bridges.

Too much pains cannot be taken in deciding on the line of a road. Should the line be ill chosen, great expense may be incurred in constructing the road, and keeping it in repair; and it may eventually be found more economical to lay out a new line altogether, although it will involve the abandonment of the work already done on the old line. On the other hand, if the road has been skilfully laid out, although it may not be expedient at the time to go to any great expense in bridging the streams and improving the surface; still, whatever is done will be a step in the right direction, and nothing will afterwards have to be undone.

159. The following Memoranda, by an experienced Road Engineer, on this important subject will be found valuable.

The *average section of our Imperial roads in Upper India may be taken at as follows*:—

Breadth of top of embankment, 40 feet.
Height of embankment, 4 feet.

Slopes, 5 horizontal to 1 perpendicular.

Breadth of arches of bridges, 30 feet.

Breadth of metal, 16 feet by 9 inches thick.

Rate of earthwork, Rs. 2-8 per 1,000 cubic feet.

Rate of consolidated metal, per inch per mile, Rs. 750.

Cost of maintenance, per mile yearly, Rs. 750.

Cost of drain bridges, per running foot of water-way, from 75 to 100 Rs. up to 15 feet span.

Cost of large bridges, from 300 to 400 Rs. per foot.

The rates here given will be found a close approximation to the actual cost, only that for earthwork is rather over than under what the probable expenditure may be.

From the above data we obtain the following comparative cost of embankments, bridges and metal.

Cost of one mile of embankment $(40 + 20) \times 4 = 240$, @ Rs. 2-8 per $1{,}000 = 0{\cdot}60$ or Rs. 0-9-7 per foot.

$\therefore$ One mile cost $5280 \times 0{\cdot}60 =$ Rs. 3,168.

The cost of drain bridges is $\frac{75 + 100}{2} =$ Rs. 87·8 per foot.

Therefore, the cost of one mile of embankment equals only 36 feet of water-way for drain bridges, while only 10 running feet of water-way of such bridges as that over the Maikunda equal the cost of one mile of embankment.

One mile of metal costs $750 \times 9 =$ Rs. 6750, or more than double the embankment; and taking the maintenance of road, at Rs. 700 a year for metal, and Rs. 50 for earthwork, at 20 years' purchase, we have for metal $700 \times 20 =$ Rs. 14,000 a mile; therefore the cost of metal is Rs. 20,750 a mile, or more than six times the cost of the embankment.

From the above, therefore, it is evident—First, that all cross drainage should be avoided where practicable, and that *the height of embankments should not be so much taken into consideration as the length of road*, so as to save metal.

Secondly, as the cost of metal is such an important item, and as this so much depends on the distance from the quarries in selecting a new line, *the proximity to kunkur beds should form a very great reason for adopting one line in preference to another.*

Supposing the wear and tear of metal to be 7,500 cubic feet a year per mile, and that 8 annas is saved for each mile the road is nearer the quarries, the actual saving would be 7,500, @ Rs. 0-8 = Rs. 37-8 a mile, which at 20 years' purchase equals Rs. 750. Thus, if 4 miles could be saved in carriage, it would equal the first cost of the embankment nearly; or the road may be lengthened one-sixth between two points without adding to its cost; that is 16·66 per cent. longer, which would admit of a diversion of about one-third of the total distance out of the straight line.

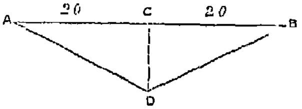
Lastly, where nothing is to be gained by deviating from the straight line, either in avoiding drainage or being nearer kunkur beds, the embankment may be raised as follows, without adding to the cost of the road, with the following rates for earthwork :—

Height of embankment up to 5 feet, Rs. 2-8 per 1000,
„ „ above 5 and up to 10, Rs. 3 per 1000,
„ „ 10 and up to 15, Rs. 3-8 per 1000,

Saving in distance	1	mile in	2,	or	$\frac{1}{2}$,	embankment may be raised to	18·00	feet,
	1	,, ,,	3,	,,	$\frac{1}{3}$,	,,	10·00	,,
	1	,, ,,	4,	,,	$\frac{1}{4}$,	,,	8·40	,,
	1	,, ,,	5,	,,	$\frac{1}{5}$,	,,	7·45	,,
	1	,, ,,	6,	,,	$\frac{1}{6}$,	,,	6·64	,,
	1	,, ,,	7,	,,	$\frac{1}{7}$,	,,	6·10	,,
	1	,, ,,	8,	,,	$\frac{1}{8}$,	,,	5·80	,,
	1	,, ,,	9,	,,	$\frac{1}{9}$,	,,	5·50	,,
	1	,, ,,	10,	,,	$\frac{1}{10}$,	,,	5·33	,,
	1	,, ,,	15,	,,	$\frac{1}{15}$,	,,	5·00	,,

That is, *if the road can be shortened $\frac{1}{20}$ to $\frac{1}{15}$ of its length, add one foot to height on an average throughout the whole length of embankment*; from $\frac{1}{15}$ to $\frac{1}{9}$, add $1\frac{1}{2}$ feet; from $\frac{1}{9}$ to $\frac{1}{7}$, add 2 feet; for $\frac{1}{6}$ and $\frac{1}{5}$, add 3 feet; if $\frac{1}{4}$ is gained, add $4\frac{1}{2}$ feet; where $\frac{1}{3}$, add 6 feet; and where the distance is halved, add no less than 9 feet to the height of embankment. *That is, supposing a valley to intervene*, which is one mile broad and requires an embankment averaging 13 feet high to cross it, but by going a circuitous road which would avoid this bad ground, but add one mile to the length of the road (all other circumstances remaining the same along the line), it is as *cheap* to make the 13 feet embankment as to go the more circuitous route, while travellers are saved one mile. In other words, it is very seldom a road should be made to deviate from the straight line on account of earthwork only, except in a hilly country where steep gradients would interfere.

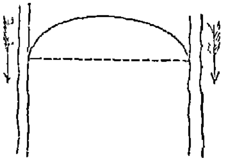
Considerable deviations can however be made from the straight line without adding much to the actual length of road, as will be seen by the following:—Let A and B be (say) 40 miles apart, and half way, at the point C, lay off the perpendicular line CD. Suppose CD is one-tenth of AB, the line ADB will only exceed AB 2 per cent. The Engineer, therefore, at half the distance between the two points to be connected, has a breadth of 8 miles to select from, without adding more than 2 per cent. to the whole length of road. If $\frac{1}{6}$, or 16·66 per cent. be added, (the limits where the cost of embankment and maintenance of metal equal each other,) the divergence may be upwards of 13 miles on either side. Such a deviation from the straight line is much too great; so, in practice, if cross drainage can be saved to the extent of saving only 14 square miles in a distance of 40 miles, it comes to the same thing as to cost, as adding 2 per cent. to the length.



Thus, Rs. 3,168, cost of one mile.

$$\times \frac{(2 \text{ per cent. on } 40 \text{ miles} = 0{\cdot}8) \times 7 \text{ (cost of earthwork and metal)}}{87{\cdot}5 \text{ (cost of one foot of water-way)}} = 202{\cdot}7, \text{ and}$$

by page 135, of Vol. II. of Professional Papers, Colonel Dickens allows 42 feet of water-way for 3 square miles; but, by adding 2 per cent. to the length, we do not merely gain 14* square miles, but $\frac{40 \times 4}{2} = 80$ square miles, where the road runs at right angles to the drainage. Therefore, there can be no doubt that where we have a road (say) crossing from the Ganges to the Jumna (all other points being the same), that instead of it being a direct line right across, it should curve considerably upward, thus—



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* $\frac{202{\cdot}7 \times 3}{42} = 14$ square miles.

The extent of deviation in a distance of 40 miles, and the per centage added to the length of road is here given :—

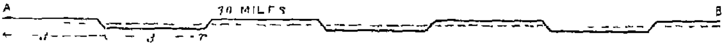
	Miles.		Per centage.
1	in	40 =	0·15
2	„	40 =	0·30
3	„	40 =	1·24
4	„	40 =	2·00
5	„	40 =	3·00
6	„	40 =	4·27
7	„	40 =	5·62
8	„	40 =	7·11
9	„	40 =	8·80
10	„	40 =	11·00
11	in	40 =	12·41
12	„	40 =	14·28
13	„	40 =	16·18
14	„	40 =	18·10
15	„	40 =	20·00
16	„	40 =	22·12
17	„	40 =	24·18
18	„	40 =	25·60
19	„	40 =	27·51
20	„	40 =	29·33

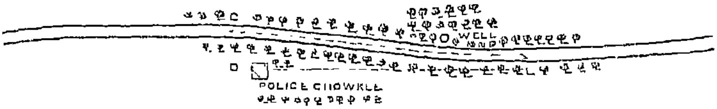
From which it appears, that so long as the deviation is kept within moderate distances, the additional length is little ; for even up to one-fourth of deviation of the total distance, only 11 per cent. is added ; but where this is exceeded, the per centage increases fast.

Suppose the bearing between the two points to be connected is 90°, or due east and west ; so long as the bearing of no part of the line does not exceed 100° or less than 80° for all practical purposes the road will be nearly as short as the direct line, while it gives the Engineer considerable scope for selecting his line. In doing which, he should consider, first, the Drainage ; secondly, the supply of Metal ; and lastly, the Earthwork, which, though at first sight it appears the greatest, is in reality insignificant in comparison to the other two items.

A straight line is undoubtedly the shortest distance between two points, but nothing is more monotonous than to have to march along a straight road. In fact, one should never be able to see more then three miles along any road ; and this can be easily accomplished by passing round a village or a clump of trees. Curves, however, are unsightly in an open plain, unless there be some natural feature in the country necessitating a curve, such as to cross a stream at right angles, or to avoid low, marshy ground, or some high mound. In the latter case the mound can be taken advantage of in hiding the road. Where, however all is one extensive plain as one often meets with in India, to put a curve in a road and not to *hide* it, appears as if a mistake had been made in lining it out, which is worse than a continuous long line.

Curves may however be given at every three miles, so that no portion of the road can be seen for a greater distance, and the road greatly improved, not only in appearance, but also in comfort to travellers. Suppose the distance between the two points it is necessary to connect is 30 miles apart, and that the country is one open uniform





plain. The shortest line would no doubt be one uniform straight, but it would be too tedious, and would involve long marches of 15 miles each, with nothing to break the monotony of the march. By introducing Ogee or S curves at every three miles, and planting two clumps of trees near them on either side of the road, with a well in the centre of one of them, *the road could only be seen along three miles of its length.* and wearied travellers would have comfortable shade with water to drink. A Police Chowkie could be placed in the other clump, so as to afford protection to property.

Supposing DE to be equal to 1000 feet, and CD equal 50 feet, then $\sqrt{1000^2 + 50^2}$ $= 1001{\cdot}24$ feet; or nine of these curves may be introduced and only add to the length of the road in a distance of 30 miles, some four yards.

160. *Gradients.*—Every road should be theoretically *perfectly level.* If it be not, a large portion of the strength of the horses which travel it will be expended in raising the load up the ascent. When a weight is drawn up an inclined plane, the resistance of the force of gravity, or the weight to be overcome, is such a part of the whole weight as the height of the plane is of its length. If then, a road rises one foot in every twenty of its length, a horse drawing up it a load of one ton, is compelled to actually lift up one-twentieth of the whole weight, *i. e.*, one hundred pounds, through the whole length of the ascent, besides overcoming the friction of the entire load.

The following table is the result of experiments.

Calling the load which a horse can draw on a level 1·00, on a rise of—

1	in	100	a horse	can draw	only	·90
1	„	50	„	„	„	·81
1	„	44	„	„	„	·75
1	„	40	„	„	„	·72
1	„	30	„	„	„	·64
1	„	26	„	„	„	·54
1	„	24	„	„	„	·50
1	„	20	„	„	„	·40
1	„	10	„	„	„	·25

In round numbers, upon a slope of 1 in 44, or 120 feet to the mile, a horse can draw only three-quarters as much as he can upon a level; on a slope of 1 in 24, or 220 feet to the mile, he can draw only half as much; and on a slope of 1 in 10, or 528 feet to the mile, only one-quarter as much.

This ratio will, however, vary greatly with the nature and condition of the road; for, although the actual resistance of gravity is always *absolutely* the same upon the same inclination, whether the road be rough or smooth, yet it is *relatively* less upon a rough road, and does not form so large a proportional part of the whole resistance.

Thus, if the friction upon a road were such as to require, upon a level,[*] a force of draught equal to one-fortieth of the load, the total force required upon an ascent of 1 in 20, would be $\frac{1}{40} + \frac{1}{20} = \frac{3}{40}$. Here, then, the resistance of gravity is two-thirds of the whole.

If the road be less perfect in its surface, so that its friction $= \frac{1}{20}$, the total force upon the ascent will be $\frac{1}{20} + \frac{1}{20} = \frac{1}{10}$; and here, then, the resistance of gravity is one-half of the whole.

If the friction increase to $\frac{1}{10}$, the whole resistance is $\frac{1}{10} + \frac{1}{20} = \frac{3}{20}$; and here, gravity is only one-third of the whole.

We thus see that on a rough road, with great friction, any inclination forms a much smaller part of the resistance than does the same inclination on a smooth road, on which it is much more severely felt, and proportionally more injurious; hence we deduce that steeper gradients are allowable on *kucha* than on *pucka* roads.

The loss of power on inclinations, is indeed even greater than these considerations show; for beside the increase of draught caused by gravity, the power of the horse to overcome it is much diminished upon an ascent, and in even a greater ratio than that of man; owing to its anatomical formation and its great weight. Though a horse, on a level, is as strong as five men, yet on a steep hill it is less strong than three; for three men carrying each 100 lbs., will ascend faster than a horse with 300 lbs.

161. Inclinations being always thus injurious, are particularly so where a single steep slope occurs on a long line of road, which is comparatively level. It is, in that case especially important to avoid or to lessen this slope, since the load carried over the whole road, even the level portions of it, must be reduced to what can be carried up the ascent. Thus, if a long slope of 1 in 24 occurs on a level road, as a horse can draw up it only one-half of his full load, he can carry over the level parts of the road, only half as much as he could and should draw thereon.

This evil is sometimes partially remedied by putting on a full load and adding extra horses at the foot of the steep slope. Oxen are thus employed to assist carriages up steep hills, in many countries. But this is an inconvenient, as well as an expensive system, and the truest economy is, to cut down, or to go around such acclivities, whenever this is possible.

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[*] See page 174.

162. The loss of power on inclinations being so great, as has been shown, it follows that it is very important never to allow a road to ascend or descend a single foot more than is absolutely unavoidable. If a hill is to be ascended, the road up it should nowhere have even the smallest fall or descent, for that would make two hills instead of one; but it should be so located and have such cuttings and fillings, as will secure a gradual and uninterrupted ascent the whole way.

In this point Engineering skill can make wonderful improvements. Thus, an old road in Anglesea, laid out in violation of this rule, rose and fell between its extremities, 24 miles apart, a total perpendicular amount of 3,540 feet: while a new road laid out by Telford between the same points, rose and fell only 2,257 feet; so the 1,283 feet of perpendicular height is now done away with, which every horse passing over the road had previously been obliged to ascend and descend with its load. The new road is, besides, more than two miles shorter.

163. The importance of the question of gradients being thus established, it may be sufficient to say that the result of a large number of cases, seems to show that a gradient of 1 in 30 is the maximum slope that is desirable on any metalled road.

When inclinations are reduced to this limit, there is little loss of power, compared with a perfect level in either direction of travel; for the increased labor of ascending is compensated in a great degree by the increased ease of descending, while on a steeper slope this advantage is nullified by the necessity of the animals holding back the vehicle to resist the excess of the force of gravity.

Any steeper slope than the above, therefore, entails a waste of animal power in ascending, and a certain amount of danger in descending, and should only be justified on very strong grounds. Of course there are many cases in which such grounds arise, principally in connexion with the question of expense; as for example in Hill Roads. But all such cases should be regarded by the Engineer as exceptional. And if on otherwise level lines it may be necessary to have steep gradients here and there, he will make them as short as possible.

On a *Kucha* Road, for the reason stated above, steeper slopes may allowed, even to 1 in 20.

164. It is not desirable in practice that any road should be on a dead level, as its surface could not be kept free from water without giving it so great a rise in its middle as would expose vehicles to the danger of overturning. But when a road has a proper slope in the direction of its length, not only do the side-ditches readily discharge the water which falls into them, but every wheel-track that is made becomes also a channel to carry off the water. This minimum slope, below which it is not desirable that a road should be levelled, may be fixed at 1 in 125, and in a perfectly level country the road should be artificially formed into gentle undulations approximating to the minimum limit.

The following tables of corresponding angles and inclinations will be found useful.

Angles.	Inclinations.	Feet per mile.
½°	1 in 115	46
¾°	1 in 76	69
1°	1 in 57	92
1½°	1 in 38	138
2°	1 in 29	184
2½°	1 in 23	231
3°	1 in 19	277
4°	1 in 14	369
5	1 in 11	462

Inclinations.	Angles.	Feet per mile.
1 in 10	5° 43′	528
1 in 13	4° 24′	406
1 in 15	3° 49′	352
1 in 20	2° 52′	264
1 in 25	2° 18′	211
1 in 30	1° 55′	176
1 in 35	1° 38′	151
1 in 40	1° 26′	132
1 in 45	1° 16′	117
1 in 50	1° 9′	106
1 in 100	0° 35′	53
1 in 125	0° 28′	42

165. *Cross Section.*—The proper width must depend on the amount of traffic; the least width being 16 feet, to enable two vehicles to pass with ease; but in practice, roads are rarely made of a less width than 20 feet. In this country it is customary and advantageous to have a central width metalled (usually 16 feet) and two side widths* of 12 feet, which are left *kucha* for hackeries and horsemen. This makes a total width of 40 feet for the surface, which is sufficient for any first class road. Beyond the slope of the cutting or embankment on each side, a space of some 50 feet in breadth is usually taken, on which material can be stacked for the repairs of the road, and beyond this space again are the ditches which serve as a boundary and for drainage.

On inferior roads, however, or where land is valuable, the breadth of the kucha portion on each side of the metalling may be reduced to 7 feet, and the extra space beyond the side slopes may be dispensed with altogether. The ditches on each side should be triangular in section, or nearly so, and may be 3 to 5 feet wide at top, and 1 to 3 feet deep, according to the amount of drainage water they are likely to receive. Cross drains should be made from them, wherever feasible, leading to the natural water-courses of the country, and they should be periodically cleared out to let the water run freely. The slope of their bottom should not be more than $1\frac{1}{2}$ to 3 feet per mile, otherwise they are apt to be cut up by the water and to become worse than useless. On this account, indeed, many engineers object to side ditches at all, but there seems no reason for this if they are properly made and cared for.

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* These side widths should be kept clear of all material—as cart-men, especially on long journeys, prefer them to the metalled part, being much easier for the feet of the cattle. The metal may be 20 feet wide where the traffic is very great.

166. *Trees* whether in rows or *topes* should be outside the ditches, and always planted well back from the road, otherwise the droppings from the leaves will injure the surface,* and their shade will keep it from drying properly. On this account, as well as from the difficulty of properly attending to long lines of trees, it is better to plant them generally in topes or clumps, here and there, which are also perhaps more useful to travellers encamping, while avenues may be reserved for the neighbourhood of stations or towns where they can be better attended to. In all cases they must be defended by a circular wall of mud or (what is better) of wicker work, for the first three years of their growth. The Mango, Sissoo, Siris, Peepul, Banian, Tamarind, Ním, and other varieties, may be enumerated as proper for roadside trees in Upper India.

167. The *Side Slopes* of cuttings and embankments vary with the nature of the soil, but the made earth of the latter requires a more gentle slope than the former. Rock cuttings may be left vertical; stiff clay will stand at 1 to 1 or 45°. Wherever turfing is practicable at a moderate cost it should be carried out, especially for embankments, which otherwise will require a slope of 2 or 3 to 1; cuttings will in general adjust their own slopes and should be allowed to do so where there is room, before the road is open for traffic.

The formation and calculation of embankments and cuttings will be described hereafter. If their height or depth is great, it may be necessary to reduce the breadth of road surface below what has been given above, in order to save expense, and as the metalled portion should not be less than

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* This applies more especially to Macadamized roads. In kunkur roads it seems doubtful whether the trees do not do more good than harm, in such a climate as that of Upper India, by protecting the surface from the extreme dry heat.

16 feet, the surface width may vary between that and 40 feet according to the cost.

The shape of the road bed should be two inclined planes meeting at the centre and rounded off, the fall from the centre towards the sides should not exceed $\frac{1}{2}$ an inch to a foot, or 1 in 24.

In a road round a hill, the cross section should be a single slope inclining inwards with a ditch on the inside, this is to prevent the road being washed away at its edge (which often has to be built up) and to avoid the danger, especially in turning a corner, of the passengers falling over the *khud.* The drainage water, flowing from the hill above, is also intercepted by the ditch on the inside, which has cross drains at intervals leading under the roadway to the face of the cliff.

168. *Metalling.*—The primary object of hardening the road surface, is to diminish friction. The power of draught necessary to overcome the friction of the wheels of a vehicle under certain circumstances, is called *the force of traction,* and its amount in fractional parts of the weight moved, has been determined by experiment for different road surfaces, and varies from $\frac{1}{16}$ on a kucha road to $\frac{1}{51}$ on a good macadamized road. And it may be concluded that taking the greatest load that can be drawn by an animal on a level kucha road as the standard, the same animal would draw on a good macadamized road *three* times as much ; on a kunkur road in perfect repair, *four* times ; on a Railway, *eighteen* times.

Besides diminishing the labor of draught and saving the wear and tear of vehicles, the metalling should also act as a water-tight covering to the road itself, and thus preserve it from injury by rain. Perfect metalling should combine the advantages of being smooth, hard, tough and binding, and should be laid on an unyielding surface. The last condition will in general, be fulfilled by laying the material in sufficient thickness on firm earth that is properly drained, and has had time to consolidate. The other three conditions are more or less met by the various substances used as metalling—such as stone, kunkur, and bricks, besides wood, asphalte, and one or two others which are not employed in India. In general the proximity of the material practically determines the particular kind that shall be adopted.

Stone.—The hardest kinds are the best, such as granite, trap, and the hard limestones and sandstones. Stone may be used either in large blocks or in small pieces rammed together; the former is more suitable for a town;

the latter known as *macadamizing*, is suitable for all first class roads, and will stand heavy traffic well when properly laid down.

Laterite, which is a species of indurated clay or soft rock, is used very much on the Madras roads, but will not stand much traffic, being too soft.

Gravel is also used in Madras, and makes a tolerable metalling for a second or third class road; it is in general not procurable in Upper India; if mixed with chalk or lime into concrete its quality as a road material is very much improved.

Kunkur, which is the material chiefly used in Hindoostan, is a peculiar formation of oolitic limestone—found generally in nodules, sometimes in masses a little below the earth's surface; it makes an excellent road, but requires constant repair if the traffic is at all heavy. The best is found in the neighbourhood of Allyghur, where it is dug out in large blocks and even used as building stone. The breaking of this block kunkur entails a good deal of expense, and if not broken at once when quarried, it becomes very tough and difficult to break afterwards.

Roads metalled with this kind of kunkur are very apt to be *lumpy* unless great care be taken to have the metal properly broken. It wears exceedingly well, however, when properly sized and laid.

Brick makes a tolerable metalling when no other is available, but only the very hardest kinds should be used.

In the Bombay Presidency, the chief material used in Road making is *Moorum*; as it is generally obtained close at hand at small cost, and affords the best sort of materials with which to commence a new road.

The term moorum, is applied to almost all descriptions of sub-soils which are suited for the surface of a road, by being at all harder than the common earth, and the surface of a moorumed road may contain in it different portions of sand, laterite, broken bricks, kunkur, yellow earth, or any hard strata, which may be met with below the surface.

The real moorum is probably rock in course of disintegration. It is met with at a depth of 2 or 3 feet in regular strata, and is nearly homogeneous in the same locality. It varies, however, in different localities, at almost every mile, both with respect to its hardness and durability, as well as the size of the pieces into which it breaks. It is got with the pickaxe, and the very hardest moorum therefore that can be obtained must fall considerably short of metal. The usual form in which this material breaks is into flakes or clinkers, with sharp well defined edges; this sort is a favorable description for binding under pressure and moisture. There is another very good description of moorum which comes out in small blocks or nodules, nearly the size of a man's fist; this kind is very difficult to bind, but when once well consolidated, it makes a strong and good roadway. A third description of moorum, differing from either of the above is of a gravelly nature. It breaks up into small pieces, and forms a very smooth pleasant road in the fair season, well adapted for carrying light traffic, and does for cantonment roads. It is, however, not sufficiently strong to stand heavy traffic well, and in the rains it is not much better than an earthern road.

The method of applying the above materials will be treated of further on.

168a. Subjoined are specifications for the new roads now constructing in the Province of Rajpootana, drawn up by Major Pollard, Superintending Engineer.

General Description.—Roads will be divided into four classes. Classes 1 and 2 will be metalled and bridged up to a certain fixed water-way, and will differ merely in width, both being adapted for quick traffic in all weathers.

A 3rd class road will likewise be available for traffic in all weathers; but the metalling of the road-surface will be inferior, and the larger bridges suited for a single line of traffic only.

A 4th class road will be unmetalled and unbridged; in fact, merely a fair-weather road on which the ground has been cleared, and the nullahs made passable. It may be regarded as a commencement of a 3rd class road.

Width of land to be taken up for roads.—The surrender of land for communication is always distasteful to the people of a country, but doubly so when the ground required is capable of producing valuable crops,—such as opium, sugar-cane, tobacco,—for which special qualities of soil are required. When such land is of necessity absorbed within the road limits, it is advisable to reduce the width to a minimum, without prejudice to the absolute requirements of the highway. This is simply managed by diminishing the side gutter, and giving up its exterior slope altogether. In the specifications, therefore, two breadths are shown,—the narrower of which should be adopted where the land is of more than ordinary value.

Specification of a 1st class road (See Figures 1, 2, 3). For a 1st class road, in ordinary land, the width required is 108 feet, divided as follows:—

Roadway, ...	30 feet.
Side slopes, 2 × 4, ...	8 „
Berm or cess, 2 × 15, ...	30 „
Side trenches, 2 × 20, ...	40 „
Total, ..	108 feet.

This has been calculated from the requirements of a two-foot embankment, with side slopes of 2 to 1. If the embankment exceeds two feet, the extra width for the base of the slopes must be taken from the cess.

In valuable land the width may be reduced to 78 feet as follows :—

Roadway, ...	30 feet.
Side slopes, 2 × 4, ...	8 "
Berm or cess, 2 × 15, ...	30 "
Sides trenches, 2 × 5, ...	10 "
Total,	78 feet.

The general specification of a 1st class road is:—

Embankment roadway to be 30 feet wide, with side slopes of 2 base to 1 height.

Gradients not to exceed 1 in 25.

Drains and Culverts, up to 10 feet water-way, to be 30 feet between parapets.

Bridges and Culverts, above 10 feet water-way, to be 20 feet in the clear between parapets.

Metalling in black soil, or where moorum is procurable, to consist of a foundation of 12 inches of moorum, 18 feet wide, well consolidated with a top layer of 6 inches of broken stone or kunkur. Where moorum is not obtainable, and the soil hard and firm, the metalling will be 9 inches of broken stone or kunkur, 12 feet wide.

The estimate for a 1st class road should include all bridges up to 150 feet water-way Beyond this, they should be taken up as independent works, and form the subject of separate Estimates.

Specification of a 2nd Class road (See Figures 4, 5, 6*).*—For a 2nd class road, in ordinary soil, the width to be taken up is 80 feet, divided as follows .—

Roadway, ...	24 feet.
Side slopes, 2 × 4, ...	8 "
Cess, 2 × 12, ...	24 "
Side gutters, 2 × 12, ...	24 "
Total, ..	80 feet.

In valuable land the detail will be as follows :-

Roadway, ...	24 feet.
Side slopes, 2 × 4, ...	8 "
Cess, 2 × 12, ...	24 "
Side gutters, 2 × 3, ...	6 "
Total,	62 feet.

The specification of a 2nd class road is .—*Roadway* to be 24 feet wide, and in embankment to have side slopes of 2 base to 1 height.

Gradients not to exceed 1 in 20.

Drains and Culverts, below 10 feet water-way, to be 20 feet wide between parapets.

Bridges and Culverts exceeding 10 feet, to be 18 feet between parapets

Metalling in black soil to have a moorum foundation 12 inches thick, 15 feet wide, and a top layer of broken stone or kunkur 9 feet wide and 6 inches thick. In firm soil, where broken stone or kunkur is used, the width will be 9 feet, and thickness 9 inches The estimates of a 2nd class road should include all bridges up to 100 feet water-way.

Specification of a 3rd class road—(See Figures 7, 8, 9*).* The land to taken up for 3rd class roads under ordinary circumstances, is 72 feet, reducible in valuable land to 54 feet.

The detail of the various parts are :—

Roadway,	.. ..	20 feet.
Side slopes, 2 × 4,	.. .. ..	8 „
Cess, 2 × 10,	.. ..	20 „
Side gutters, 2 × 12,	.. .. ..	24 „
	Total, ..	72 feet.

And the decrease, when necessary, can be made by reducing the width of the side gutters to 3 feet, as has been shown in the specification of a 2nd class road.

The general specification is, *roadway* to be 20 feet wide, with side slopes of 2 to 1.

Gradients not to exceed 1 in 20.

Drains and Culverts, up to 10 feet water-way to be 18 feet between parapets.

Bridges and Culverts, above 10 feet water-way, to be 14 feet between parapets.

Metalling, where moorum is obtainable, to be of that material exclusively, 14 feet wide and 9 inches thick. Where broken stone or kunkur is used, to be 9 feet wide and 6 inches thick.

The estimate for a 3rd class road should embrace all bridges up to 75 feet water-way.

Specification of a 4th class road.—For a 4th class road, land should be taken up 54 feet wide, and the boundary marked by a small trench. It will not be embanked, but should necessity demand it, it can hereafter be completed as a 3rd class road, of which it is only the commencement.

Its specification is :—

All ground between the boundary trenches to be levelled and cleared : nullahs to be rumped, and made passable for wheeled traffic. All hills or ghâts to be reduced to a gradient not exceeding 1 in 18.

Probable cost per mile.—The cost of these roads will naturally vary according to localities, but it may be set down roughly as follows :—

1st class road, per mile,	.. ..	Rs. 14,000
2nd class road, ditto,	.. ..	„ 10,000
3rd class road, ditto,	.. ..	„ 6,000
4th class road, ditto,	.. ..	„ 1,000

A 1st class road being expensive, is only adapted for an artery, connecting the principle Military Depôts ; for a main Postal line ; or the chief Commercial outlet of the country, where the traffic is such as to warrant the outlay.

A 2nd class road may be adapted to connect the smaller Military Stations with their Reserves, and with each other. It is also suitable for connecting Commercial Marts with the main line, or the chief outlet for their exports, whether this be a 1st class road or railway ; whilst

A 3rd class road will be found to suffice for the internal communication of the country between the more populous towns. It will also be found a useful style for short railway feeders ; and where a road is required as an outlet for an isolated district.

A 4th class road must be looked on merely as a preparation for a 3rd class line.

Unless greatly favored by nature, it will be impassible in the rains ; but for eight months of the year, it will be found a useful adjunct in many ways, not the least of which will be its habituating the people of the country to the necessity of setting apart a portion of their land for communications.

COMPARATIVE STATEMENT, *showing the dimensions of the various classes of Roads proposed for Rajpootana and Central India.*

Class of Roads.	Width of land to be taken up.		Width of roadway.	Width of Bridges and Culverts beween Parapets.		Width of Metalling.		Maximum Gradient.
	In ordinary land	In valuable land.		Up to 10 feet water-way.	Above 10 feet water-way.	Moorum foundation.	Broken stone or kunkur.	
1st Class road, ..	108 ft.	78 ft.	30 ft.	30 ft.	20 ft.	18′ × 12″	12′ × 6″	1 in 25
2nd Class road, ...	80 ft.	62 ft.	24 ft.	20 ft.	18 ft.	15′ × 12″	9′ × 6″	1 in 20
3rd Class road, ...	72 ft.	54 ft.	20 ft.	18 ft.	14 ft.	14′ × 9″	..	1 in 20
4th Class road, ...	54 ft.	54 ft.	..	..	..	..	..	1 in 18

CHAPTER XXXVI.

SURVEY, DESIGN AND ESTIMATE.

169. In laying out a road in an old country which has been long inhabited, and in which the position of the various towns is already determined, we are left less at liberty in the choice and selection of the line of road, and must be guided in that choice by different considerations, to those which would determine the route if made through a new country, where our only object was to establish the easiest and best road between two distant stations. In the first case we should take into consideration the position of the various towns, &c., situated near the intended road, and its course would be to a certain extent, controlled thereby; while in the second case, we should simply examine the physical character of the country, and base all our proceedings on the result. Whichever of these two cases however may have to be dealt with in the ultimate selection and adoption of the line of road, between these points which are fixed by other circumstances the same careful examination of the physical character of the country should be made, and the same principles should control the choice.

The first step to this is the reconnoissance or survey. From an inspection of the best maps, the general line of a road may in most cases be determined. And on this general line particular points will be found through which the road *must* pass; these obligatory or guiding points would be for instance a low gap, ghât, or pass in a range of hills that has to be crossed; a narrow part of a river suitable for a bridge, a favorable place for crossing a *jheel*, &c. Between these points, one or more trial lines will be chosen, deviating from the straight where local impediments intervene, or according to the judgment of the Engineer, who should walk over them backwards and forwards and examine them carefully map in hand.

Where the maps are not in sufficient detail, it would be necessary to select points to the right and left of the imaginary line of road, to connect them by a careful theodolite triangulation, and to fill in details by plane table and compass, so as to have an accurate survey of the belt of country, more or less wide, through *some* part of which the line would evidently have to pass. Or, a separate survey must be made of each trial line by a Theodolite traverse, the villages and other important points being laid in by cross-bearings with the compass. With the several trial lines all plotted on paper to the same scale, a good map will be obtained from which the exact line of road can then be selected.

This will be now carefully traversed and levelled—the levels being taken at regular intervals (from 100 to 500 feet apart according to the nature of the ground) and cross levels at all important points, such as where the ground slopes sideways, where a hill or stream or swamp is passed, where in fact any peculiarity renders a deviation probable or that extra expense will be necessary. The number and nature of his bridges will then be decided from a due consideration of points which have already been described in the Section on Bridges; the nature and description of culverts and drains; of metalling; of turfing for side slopes; of tree-planting; mile-stones; &c., will all have to be considered and provided for in the estimate, which, with the accompanying plans and sections, can now be prepared.

170. Having thus gone over the necessary steps from the survey of the country to the finished estimate, we may consider one or two of the steps in detail.

It will of course, often occur that no trial lines are necessary; the route to be taken by the road being apparent. In few cases will more than two be needful; and the final line selected may be one or the other, or a modification of either, according to circumstances.

In passing from one guiding point to another, our line of road may run,—1st, Across a valley to connect two points in two chains of hills; or 2nd, Across a chain of hills to connect two points in two valleys; or 3rd, To connect two points in the same chain of hills; or 4th, To connect two points in the same valley.

In the first case it will in general be found less expensive to make a considerable detour, so as to cross the valley and its drainage water towards the narrow head, instead of running the road straight across with heavy embankments and expensive bridges.

In the second case, also, the line of road will in general deviate much from the straight by having to ascend and descend the hills on each side of the pass, by such zig-zags as may meet the requirements of the ruling gradients.

The third case will comprise roads entirely through hills; and the fourth case, those running entirely through plains, being the simplest, and also in India, most general cases of all. In the third case, so long as the two points to be connected lie on the same side of the ridge, (which is the most common case,) the road would run at the *foot* of the hills, so as to cross all the water-courses where they issued from the hills; to save heavy and difficult work; and to accommodate the inhabitants who would be at the foot of, rather than *on*, the hills.

171. *Longitudinal sections.*—These will be prepared from the levels taken on the final, and if necessary, the trial, lines. For the latter they need only be in sufficient detail to enable a fair approximation to be arrived at, as to the comparative cost of the earthwork, and as to the gradients that will be required on each. The method of determining these points will be the same in both cases, and will be discussed further on.

For the final line, the working section should be made on a horizontal scale, of not less than 500 feet to the inch, and a vertical scale of 20 feet to the inch. The level of the surface of the ground above the datum, at every point where the levels have been taken, *i. e.*, at every 100 feet, should be figured in on the section; and the depth of cutting or height of embankment, at the same points, should be given in another column. This is obtained by taking the difference between the levels of the surface of the ground and the level of the road. The latter, known as the *formation surface*, is fixed on the section by a due consideration, 1st, Of the gradients necessary; 2nd, Of the importance of keeping the road surface clear of inundation; and 3rd, Of reducing the quantity of cutting and filling to a minimum. Its determination, therefore, especially if the profile of the ground be very irregular, is a matter requiring much care and thought on the part of the Engineer.

The principles for determining the question of gradients have already been given.

In order to keep the road surface above the level of inundation, it will in general be sufficient to fix it a little above the level of the highest flood marks on the ground: these may generally be determined by careful observation of the marks on neighbouring trees and houses, aided by enquiry from the inhabitants of the district. In crossing a large tract of low land, however, it must always be remembered that the road embankment will intercept the surface drainage; and though due provision may be made for passing this drainage through the road by Bridges and *Culverts*, (see below,) yet in case of heavy rain, the drainage water will be dammed against the embankment *before* it can pass through, and rise much higher than it did before the road was made. In such a case, a clear height of 3 feet should be allowed above the noted flood levels.

But, in districts where the rain-fall is heavy and the country subject to inundation, it will be necessary to make a calculation of the maximum quantity of water that will have to be passed through such embankment, by estimating the rain-fall over the catchment basin (see para. 85) and for which provision must be made in designing the bridges and culverts. This is often a very difficult task, arising chiefly from the impossibility of ascertaining at all accurately the area of the basin, and also from the shifting course of most Indian rivers, by which the spill waters of one river may often escape from their own valley and try to pass down the adjoining one. Extraordinary falls of rain too occasionally produce floods which baffle all previous calculations, and bridges are carried away and embankments heavily breached in consequence.

To guard against such accidents it is recommended to make some portions of a long embankment lower than the rest, so as to provide a safety valve for extraordinary floods, and in very dry countries where the annual rain-fall is scanty and floods uncommon, the whole roadway may sometimes be kept level with the surface of the ground, so that no risk is run or expense incurred from damming up the rain water; and the only inconvenience is perhaps a temporary stoppage of the traffic for a few hours during the year. This plan has been pursued on the Umballah and Kalka road and on the Sindh Railway.

A *working plan* should also be constructed on the same horizontal scale as the section, upon which the position of the various levelling stations should be noted, and numbered to correspond with those in the section. On this plan, the road should be drawn in of its correct width on its upper surface, and another line on each side showing the foot of the side slopes.

172. The depth or height of cutting or embankment being obtained, as above, at each point on the section, and the cross section of the road being determined by the considerations before noted under that heading, the quantity of earthwork is ascertained in the manner explained, under the Section EARTHWORK.

Where a large number of calculations have to be made, the help of Tables saves much time and trouble, and it is often useful to draw out, and prepare one's own Tables for the particular work under computation. Thus, in drawing up the estimate for a road with a uniform breadth of 30 feet, and uniform side-slopes of 2 to 1, it would save much time to calculate all possible values of the trapezoidal section for every half-foot or quarter-foot of height or depth, up to the highest likely to be used. The proper formulæ can then be used with great facility, as shown in the example given further on.

The contents of each cutting or embankment should be written upon the section. The gradients should also be noted on the line representing the formation surface.

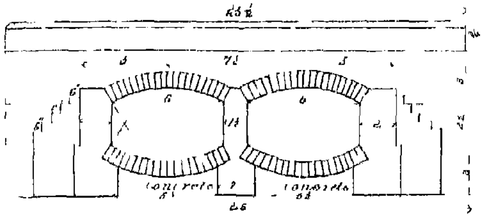
Where land is expensive and it is essential that no more ground should be taken up than that occupied by the breadth of the road, it is important that the amounts of excavation and embankment should be made to balance each other in the estimate. If the former is in too great excess, the extra quantity of earth has to be disposed of in *spoil-banks* heaped up at the sides of the road. If the excavation is deficient, earth has to be dug from the sides (called *side-cuttings*) to supply the deficiency. In either case, there is waste and expense which should be avoided if possible by raising or lowering the gradient lines of road as shown on the longitudinal section. This equalization must, however, be within certain limits, for it should evidently be abandoned when in order to fetch the earth from excavation to embankment, it would be necessary to go to such a distance, that it would be cheaper to buy extra ground close at hand for the side cuttings (technically, when the *lead* of earth exceeds a certain distance depending on the comparative cost of carriage and land).

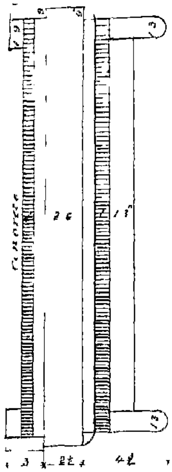
If the cuttings and embankments are to be paid for at the *same* rates, and a cutting and embankment be sufficiently close to each other to admit of the earth from the cutting being used for the construction of the embankment, *both* would not be paid for. For instance, if the embankment received the *whole* of the earth excavated from the cutting, in addition to whatever more might be in the embankment, it would be sufficient to pay for the embankment. On the other hand, if the earth from the cutting be

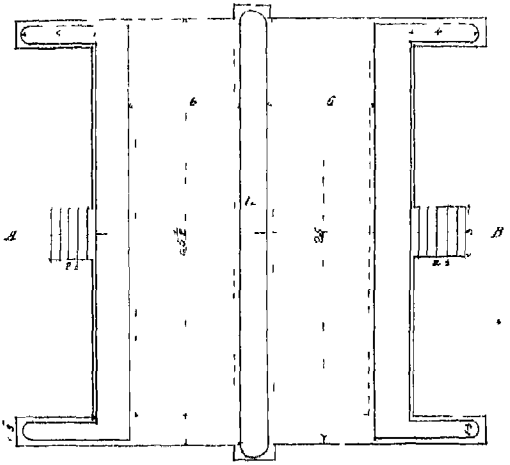
PLATE XXXVII.

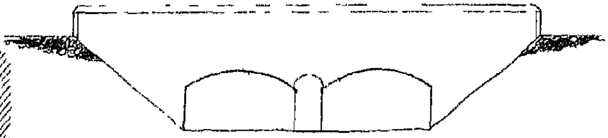
CULVERTS.

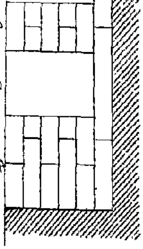
Section on A B





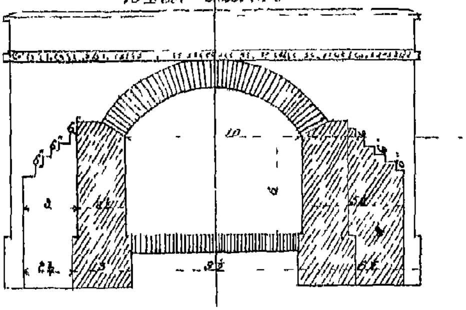






Flat topped Culvert

10 Feet Culvert



greater than the embankment can receive, the surplus being deposited in a a spoil bank, or otherwise; *it will be sufficient to pay for the cutting only*

If the cuttings and embankments are to be paid for at *different* rates, they must, of course, be taken out under separate headings in the estimate. In this case, if the rate for the embankment be higher than that for the cutting, and an embankment receive the *whole* of the earth from an adjacent portion of cutting; *it will be sufficient to pay for the embankment.*

But if the earth from the cutting be greater than the embankment can receive, the surplus being deposited in a spoil bank; then in this case the work to be paid for will be the whole of the embankment at the embankment rate, and only the portion deposited in the spoil bank, at the rate for cutting That is, the excess of the cutting over the embankment will be *paid for as cutting.*

Should the rate for cutting be the higher, a similar but inverse arrangement would be followed.

In either case, the proper quantities to be paid for at each rate should be shown in the estimate.

In calculating the quantities of earthwork in excavation and embankment, due allowance must be made for the *shrinkage* of the latter, which will vary from one-eighth in light sandy soil, to one-twelfth in gravelly earth, of the quantity excavated and thrown up into embankment; in other words, that additional quantity must be provided for in calculating what cutting is required for the finished embankments. Rock, on the contrary, occupies more space when broken, its bulk increasing by about one-half. In practice, therefore, excavations should in general exceed embankments by 10 per cent.

173. *Culverts*, are openings left in the embankment to pass the surface drainage of the country. They are usually built of masonry, and may be flat-topped, or arched, as is found most economical. Their size depends on the amount of water to be passed, but the necessary space should be given by a number of small arches, instead of one or two large ones, to prevent the embankment being unduly raised. Where the amount of water to be passed is considerable and runs in a regular water-course, a *Bridge* is necessary.

Sections and plans of culverts are given in the annexed Plate. They should be provided with floorings if there is any *rush* of water, and if the soil is bad; or if there is a great weight of embankment above, they may have inverts below the flooring, or the section may be egg-shaped.

174. In preparing the *Estimate*, the cost of the various items must be carefully worked out for the several localities. The items will, in general, be Surveying expenses, which would probably be given in a lump sum, or would be included under the head of superintendence; Lining out at so much a mile; Earthwork, at so much per 1,000 cubic feet;* Metalling, at so much per 100 cubic or superficial feet; Drains and Culverts, at so much per 100 cubic feet of masonry; Bridges (by themselves, as separate detailed estimates); Mile-stones, at so much each; Tree-planting and fencing, at so much per 100 trees; Superintendence, at so much per cent.

The cost of *Earthwork* depends, on considerations which have been already explained in Vol. I, para. 354. (See also *ante*, p. 166)

Cost of Metalling.—For a 16 feet road, the quantity of broken stone will be 16 × ·75 × 5,280, per mile, for a metalling 9 inches thick = 63,360 cubic feet. For a kunkur road, it will be 52,800 cubic feet,† the thickness being at centre 9 inches beaten to 6 inches; and at sides, 6 inches beaten to 4½ inches. Cost of each, including labor, on which more will be said presently, will vary from 2 to 3,000 Rs. per mile. One man can break about 20 cubic feet of hard stone in a day, which would be about 160 cubic feet for the rupee, or Rs. 396 per mile; besides the first cost and carriage of material and laying it on the road.

From former *Grand Trunk Road* rates it appears that kunkur was stacked by contract at the side of the road at about Rs. 1-4 per 100 maunds when brought from a distance of 1,000 to 2,000 feet. This is at the rate of nearly 500 Rs. per mile, but does not appear to have included any price paid for the material itself. The following has been supplied to me by an experienced Road Engineer, but the figures are too low for present prices.

Excavation will range from	0	15	0	to	1	8	0
Carting, (within 3 miles,) per mile, ...	0	8	0	to	0	9	0
Stacking at road side, ...	0	1	0	to	0	1	6
	1	8	0	to	2	2	9
Consolidation, ...	0	10	0	to	0	14	0
Total per 100 cubic feet of kunkur metalling carted one mile,	2	2	0	to	3	0	6

Rates of Work on the *Lucknow and Fyzabad Road*, which is still under construction, may usefully be quoted; they have it is believed been found sufficient.

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* And in hill roads, Blasting at so much per 100 or 1000 cubic feet.

† Or about 41,000, a cubic foot of kunkur weighs about 65.

Earthwork (ordinary),	at Rs. 2 per 1,000 c. f.
Do in high embankment and carried 150 yards,	at Rs 4
Turfing slopes,	at As. 4-6.
Metalling, kunkur, carried an average distance of———2 layers each 4½ inches thick,	at Rs. 5 per 100 c. f.
Pucka brick masonry set in lime, for culverts,	at Rs. 17 per 100 c. f.
Milestones,	at Rs. 16 each.

The following were the Rates of Work actually executed on the *Lahore and Peshawur Road* up to 1st May, 1853, calculated on an average of *all* the divisions :—

Earthwork,	at Rs 3-5 per 1,000 c. f
Masonry,	at Rs. 12-11 per 100 c. f.

The following were rates, at that time *estimated* to complete the above road :—

Kunkur metalling, carried for a considerable distance,	at Rs. 3,830 per mile.
Stone metalling carried from six to nine miles,	at Rs. 8,000 per mile.
Tunnel excavation,	at Rs. 20 per 1,000 c. f.
Tunnel masonry,	at Rs. 25 per 100 c. f.
Dry masonry for retaining walls,	at Rs 6 per 100 c. f.
Milestones,	at Rs. 60 each.

As to the cost of Bridges and Culverts it is evident that it must vary almost indefinitely, but on the Grand Trunk Road it has been estimated at from Rs. 75 to 100 per running foot of water-way for small bridges, and from Rs. 3 to 400 for large ones.

The following is the average cost of Macadamized Roads in the *Madras Presidency.*

Width of road,	30 feet.		
Width of metalling,	24 "		
	£	s.	d.
Cost of earthwork,	166	14	0
Do. of metalling,	163	16	0
Bridges and Culverts,	302	14	0
Sundries,	40	0	0
	£673	4	0

If an addition be made to this sum for the cost of superintendence, &c., bringing it up to £750 per mile run, this will be an ample allowance for any contingency. £55 per mile has been estimated as the annual cost of maintenance.

175. We shall next treat of the *Comparison of Cost with Returns.* This is a question that the Engineer may or may not have to consider. In general he receives his orders to construct a 1st or 2nd class road, from such a place to such a place. Often the importance of the road cannot be measured by the money returns. It may be a military road, important in a strategetical point of view, but of no great consequence to trade. Or even where made for commercial purposes, it may be difficult to show the actual gain to the makers, who in India are generally the Government; and who derive no direct advantage from it, except perhaps from tolls, which barely suffice to keep it in repair. But, as it is to be hoped that the time is not far distant, when private individuals or companies may expend part of their own resources in making roads, as a good commercial speculation, giving adequate returns, either directly in the shape of tolls, or indirectly in the saving of carriage and cost of transport of productions, it is right that the rising generation of Engineers should understand the principles of the question. First, then —That road, which is truly cheapest, is not the one that has cost the least money, but the one which makes the most profitable returns in proportion to the amount expended on it. In its construction it should of course, while violating none of the principles that have been above laid down, be so laid out as to require the least amount of expensive works, and with an eye to the proximity of the materials used in its construction.

When, however, the cost of construction has been properly estimated, the returns to be expected from it are next to be ascertained; and though these will of necessity be approximations only, yet experience has shown that the right application of principles will enable a very fair result to be arrived at. This result will be in the shape of the annual saving of labor in the carriage of goods and passengers, which the construction of the road will produce. If this annual saving exceed the annual interest of the money to be expended, (at whatever per centage the money can be obtained,) then whatever be the amount of that excess will be clear gain* to the proprietors of the road, to be taken by them in the shape of tolls; or in cheapening the carriage of their own goods. And the result so worked out from traffic previously existing, may always safely be assumed to be below the mark, as experience invariably proves that good roads are not merely a convenience to the old traffic, but will also create a very large additional traffic.

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* After paying for Road maintenance and repairs.

176. Say that it is proposed to substitute a good metalled road in place of a kucha road actually existing in any district, the road being already raised and bridged.

As a first step, returns of actual traffic must be made. These will be taken by observers stationed at different points with printed forms in their hands showing the number and description of carriages, carts and animals, whether laden or unladen, passing to and fro. They should be taken for several successive days, care being taken to ascertain whether it is average traffic or due to any special and temporary cause, such as the holding of a fair or the like.

The cost of this traffic is next to be considered. Let us neglect the question of speed and consider only the weight. Assume that the road is 30 miles long and that 500,000 maunds (of passengers, cattle, grain, &c., a very moderate amount) are annually carried. The average friction of a kucha road may be taken at $\frac{1}{10}$ of the weight. The annual force of draught required will therefore be 25,000 maunds = 2,000,000 lbs. If the average power of draught of a bullock at 1·5 miles an hour for 10 hours a day be taken at 50 lbs. there would be required 40,000 bullocks to transport the above in two days, or 80,000 in one day. And taking the daily hire of a bullock at 4 annas, the annual cost of transport of the above traffic would be 20,000 Rs.

177. Let the road now be supposed to be metalled—so that the animals would draw three times as much as before.

Then the saving would evidently be 13,333 Rs. per annum, which the carriers could afford to pay either in tolls or in paying for the metalling themselves. If the money were borrowed at 10 per cent. this would represent a capital of $1\frac{1}{3}$ lakhs, and as the cost of the metalling would not exceed 90,000 Rs. at 3,000 Rs. a mile—there would be a clear gain of 40,000 Rs.* besides the saving in time, and in wear and tear of animals and vehicles, and the profit on extra traffic which would be attracted to the good road, which might be set against the annual cost of repairs.

Next suppose the old road is only to be improved by being shortened a mile by a new alignment of part of it. Then $\frac{1}{30}$th of the original distance, and therefore labor = 667 Rs. would be saved, representing a capital of 6,670 Rs, and if the proposed diversion can be made for this sum, it should be made at once. It is clear there will be a further saving in having a mile of road less to repair.

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* Or if the money raised were their own, they would get a handsome return of 30 per cent for their money.

Next, suppose that the original road has a heavy gradient, 1 mile long, at a slope of 10 to 1 to the top of a hill, which it descends by a similar gradient on the other side; and that by making a detour of a mile, the gradient can be reduced to 30 to 1. It appears from the table, p. 169, that an animal can draw $2\frac{1}{2}$ times as much in the latter case as in the former, so that to draw the above the traffic would cost $\frac{2\,5 \times 20{,}000}{{}^{*}15}$ Rs. $=$ 3,333 Rs. more annually than with the lighter gradient; so that if the extra mile could be made for Rs. 30,000, it would be worth making.

These calculations will show the principles on which similar ones in like cases should be conducted. Some such calculations should, whenever practicable, accompany every design for a new Road. It is true, as remarked above, that the pecuniary return would be nominal, rather than real, so far as the Government was concerned, but it would at least serve to show the absolute benefit to the community that would arise from constructing or improving the road; and indirectly, no doubt a good Road is as profitable to Government as a good Canal.

178. The following Memo. will be found to bear directly on the above question.

Extract of a letter from the Post Master General, North Western Provinces, dated 30th September, 1850.—A calculation based on the returns of the Bullock Train, goes far to prove that without any reference to the general interests of the country, the want of a road to Lahore annually causes Government to incur an expense greater than would keep in repair, and pay interest on, the original cost of construction of a metalled road.

The following statement shows the actual number and weight of packages conveyed

	Miles.	Number of Packages	Gross Weight.			Cost of Conveyance.		
			Mds.	Srs.	C.	RS.	A.	P.
From Allahabad to Cawnpore, ...	125	3,594	6,002	29	9	1,748	0	0
From Meerut to Umballah, ...	128	1,992	2,929	1	0	2,632	10	8

from Allahabad to Cawnpore, and from Meerut to Umballah, in the month of May, 1850, together with the cost of establishment on each road. I have selected May as

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[*] One-fifteenth of the whole distance.

a month in which the establishment was fully employed, and one during which there are no difficulties arising from rain.

The distances are nearly equal to each other, and to the distance between Kurnaul and Loodiana; so that the comparison can be at once applied to the latter line.

The result is that the actual cost of conveying and guarding one ton of goods on the metalled road is Rs. 8-2-1,* while on the unmetalled road the cost for the same distance is Rs 25-2-6.† From these data it is easy to estimate the cost of leaving the road in its present state. The sums mentioned, merely show the actual charge of haulage in dry weather, and do not include the cost, and wear and tear of carts and wagons, or any estimate of the loss occasioned by the unmetalled road by delay caused by rain.

If the whole were completed by the British Government, the cost could hardly exceed Rs 5,000 a mile. At this rate, the total cost would be about six and a half lakhs of rupees The annual cost of keeping a metalled road in repair is I believe, about Rs 300 a mile; all establishments included. The total annual charge on the road in question may therefore be reckoned at Rs. 70,900.

Interest on 650,000, at 5 per cent, ...	32,500	0	0
Annual repairs of 128 miles, at Rs. 300 per mile, ...	38,400	0	0
Total, . .	70,900	0	0

The difference in the cost of the conveyance of each ton of goods would be as above, Rs 17-0-5.

Charge for conveying one ton on unmetalled road, . . .	25	2	6
Charge for conveyance of one ton on metalled road, . . .	8	2	1
Difference, .	17	0	5

If therefore the weight of goods, for the cost of conveying which Government is charged, amounts in the year to 4,161 tons, the whole cost of making and keeping the road in repair would be covered.

I have no means of knowing the weight which actually passes between the Provinces and Loodiana, *en route* to the Punjab, the Jullundur Doab and Ferozepore; but if Ordnance and Commissariat stores, baggage of troops, and miscellaneous articles for civil establishments, are taken into account, I conceive that on the average of years, the amount would not fall short of that indicated above.

To this must be added many advantages, money value of which cannot be shown; such as increased speed and regularity of the mails; the absence of all obstructions to the movement of troops; and the avoidance of the thousand annoyances, delays, and injuries which are now caused by a shower of rain.

It is needless to dwell on the injury to the traffic and general interests of the country, by a state of things which triples the cost of carriage, and for four months in each year practically closes all communication above Kurnaul and Seharunpore.

On the Trunk Road, a pair of bullocks can with ease drag a ton of goods. Even if therefore, a toll of 5 rupees was imposed on each cart drawn by two bullocks, the merchant and public would gain 12 rupees in each ton of goods passing between Kurnaul and Loodiana.

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* Per ton per mile, Rs. 0-0-0½. † Per ton per mile, Rs. 0-3-0¼.

179. The following shows cost of transport of (100 maunds weight of) goods one mile, by different conveyances.

Mode of transport.	Rate.			Probable distance travelled daily.	REMARKS.
	RS.	A.	P.		
				Miles.	1 md. = 80 lbs.
Ocean long voyages, ...	0	0	2·20	150	Obtained from report of State Engineer of New York for 1853.
American lakes, ...	0	0	4·76	...	
Hudson river,...	0	0	4 00	...	
Erie canals, ...	0	0	6·35	...	
Ordinary canals, ...	0	0	8 00	...	
Coal Railways, ...	0	0	11 11	80	
Favorable passenger lines, ...	0	1	8 00	150	
Passenger lines, steep gradients,...	0	2	8 25	150	
East India Railway, lowest rate,...	0	2	1 00	150	Indian rates of transport for grains and the cheapest description of goods.
Country carts, over metalled road,	0	4	0	12	
„ „ country „	0	5	4 00	12	
Indian Carrying Company over the Grand Trunk Road, ...	0	6	11·00	33⅓	
Probable rate by Navigable Canals in Upper India, ...	0	1	0	12	

NOTE.—The probable rate of interest to be charged on goods would be one anna per 100 rupees daily, or 22½ per cent. nearly (22·8 per cent.) Therefore the cost of transport of 100 maunds of grain, worth 100 rupees at prime cost, conveyed by Canals a distance of 300 miles, would be—

	R.	A.	P.
Cost of carriage of 100 maunds $\frac{300}{16}$ .. .. =	18	12	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ..	20	5	0

or nearly 20 per cent. on prime cost.

Should the rate be reduced to 8 pie a mile

The cost of carriage of 100 mds. = $\frac{300 \times 8}{12 \times 16}$ =	12	8	0
Time of transport, 25 days, at Rs. 0-1-0, ... =	1	9	0
Total, ..	14	1	0

or only 14 per cent. on prime cost.

By the lowest rate of Railway charges,

The cost would be 300, at Rs. 0-2-1, ... =	39	1	0
Add time of transport, 2 days, ... =	0	2	0
Total, ..	39	3	0

or 39 per cent. on prime cost.

By country Carts on Metalled Roads,

The cost would be 300, at Rs. 0-4-0, ... =	75	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ..	76	9	0

or 76·72 per cent. on prime cost.

By country Carts on Unmetalled Roads,

	RS.	A.	P.
The cost would be 300, at Rs. 0-5-4, ... =	100	0	0
Add time of transport, 25 days, ... =	1	9	0
Total, ..	101	9	0

or over cent. per cent. on prime cost, with no allowance made for back hire.

By Bullock Train over the Grand Trunk Road,

	RS.	A.	P.
The cost would be 300, at Rs. 0-6-11, ... =	114	3	6
Add time for transport, 9 days, at Rs. 0-1-0, .. =	0	9	0
Total, .. =	114	12	6

or *nearly 115 per* cent. over prime cost for the cheapest class of goods, and 100 per cent. over the lowest rate by canals.

Comparing the cost by Railway and by Canal, if the canal rate is one anna a mile, it is only one-half the railway rate nearly, and about one-third the railway rate if the charge be only 8 pie. Therefore, till the interest on the capital of prime cost makes up the difference owing to the loss of time by the canal, water transport would be preferred to railway carriage. That is, no goods would be sent by railway under ordinary circumstances that cost less than 14 rupees a maund, for

	R.	A.	P.
100 maunds transported 300 miles, @ Rs. 0-1-0 .. .. =	18	12	0
Interest on 100 maunds, @ Rs. 14 for 25 days, @ Rs. 0-1-0 per cent., ... =	21	14	0
	40	10	0
And 100 maunds for 300 miles, @ Rs. 0-2-1 .. .. .. =	39	1	0
Interest on 100 maunds, @ Rs. 14 for 2 days, @ Rs. 0-1-0 per cent., ... =	1	12	0
	40	13	0

Again, suppose one European Soldier costs the state £100 a-year, or Rs. 2-11-10 daily, and that he can be conveyed by rail 1,000 miles for Rs. 16 in three days, the cost to Government would be—

	R.	A.	P.
Rs. 2-11-10 × 3 .. .. =	8	3	6
Add railway charge, ..	16	0	0
Total, ..	*24*	*3*	*6*

To march 1,000 miles at the rate of 12 miles a day, without halts, would occupy 83 days, and Rs. 2-11-10 × 83 = Rs. 227-6-4; or, by a quick railway, he can be carried at nearly one-tenth the cost to Government than if he had to march, and his services are available 80 days sooner. The natural conclusion to be arrived at therefore is that both quick Railways and slow navigable Canals, are required for the protection and development of India.

180. Annexed are Plan, Longitudinal Section, and Estimate of an actual Road, which will serve as a guide to the student, and will help to explain the preceding paragraphs.

Lucknow and Fyzabad Road.—First Section from Lucknow to Nawabgunge *distance* 16½ *miles.*—The new road proceeds in a direct line from the iron bridge, Lucknow, for a distance of 500 feet, and then curves slightly through the half ruinous bazars of Mosahibgunge and Chawgunge, and thence in a direct line till within 2,000 feet of the Kookrail bridge, where it joins the old road by a gentle curve, thus saving the formation of any new embankment on the low ground near the river. In this piece of the road, nine drain bridges are required, to pass off the drainage of the country into the Goomtee, and its branch, the Kookrail.

From the Kookrail nuddee, the old road is followed up to the outskirts of the town of Chinhut, a distance of about four miles. In these four miles a good deal of embankment was raised before the mutinies of 1857, and two small drain bridges were built, some of the gradients, however, were very steep, and required alteration. In this distance, the two old bridges, and four small drain bridges, are requisite.

The road formerly went through the town of Chinhut, (as shown in the annexed plan by a dotted line,) making a large circuit for the purpose. It has been shortened by going out-side of the town. In the new piece of embankment outside the town are three drain bridges.

At a little more than a mile beyond Chinhut, is the Thakoordwara Nullah which I propose crossing by a bridge of 30 feet waterway, the foundations being on blocks. The soil is sandy to a depth of 12 feet, at which depth there is a bed of kunkur, into which the blocks will be sunk. During severe floods, the water now covers the road to some distance on each side of the bridge. A good deal of heavy embankment is therefore required here, which will extend from this nullah to another, (the Imlee bund,) one mile further on. The Imlee bund nullah is to have a bridge of 40 feet water-way. Drawings of these two bridges are given.

For the next five miles there is now no embankment, and it is requisite to raise the road in this distance to a slight extent, the height of embankment varying from 1 to 3 feet.

The next object of any importance is the Reyt nullah; across this there is an old native built pucka bridge, before alluded to, of seven arches, having a total water-way of 50 feet.

Between this nullah and the station of Nawabgunge, some embankment is required. Two bridges of 18 and 10 feet water-way respectively, will have to be constructed over small drainage channels close to the station.

Between the present civil station and the town of Nawabgunge, is the other native bridge referred to in the commencement of the Report.

It has three arches, with an aggregate water-way of 26½ feet.

Specification.—The road to be everywhere 30 feet wide at formation level, with a centre width of metalling of 16 feet; side slopes, 2 to 1, whether in cutting or embankment; ditches as shown in cross section given.

The earth to be taken from side cuttings outside the ditches, nowhere to exceed 2 feet in depth.

Side slopes to be turfed with *dhoob* grass.

Metalling to be of kunkur in two layers, each 4½ inches thick at the centre, and 3½ at the sides, to be separately consolidated. The lower layer to consist of the larger pieces not exceeding 2½ inches in diameter; the small kunkur will be kept for the upper layer, and will be washed and screened. The bed for the kunkur to be horizontal, and sunk 6 inches below the formation surface, so that the metalling, when consolidated, will be flush with the earthern sides.

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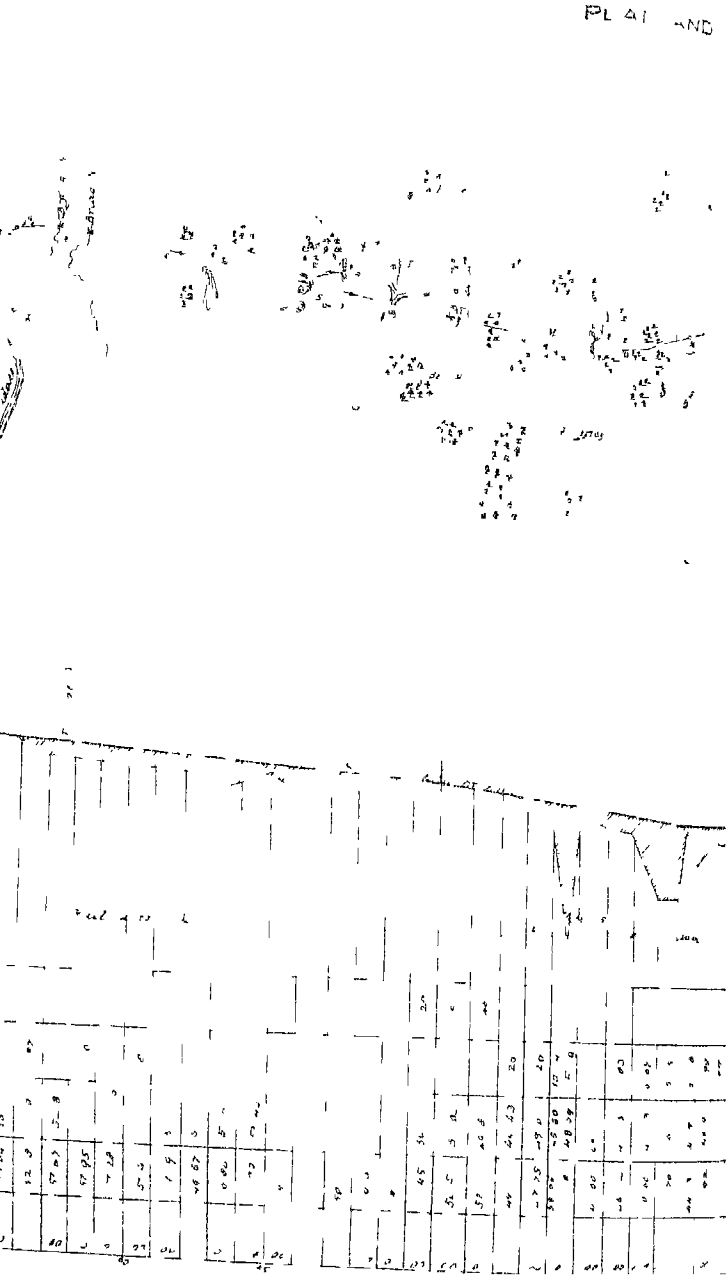
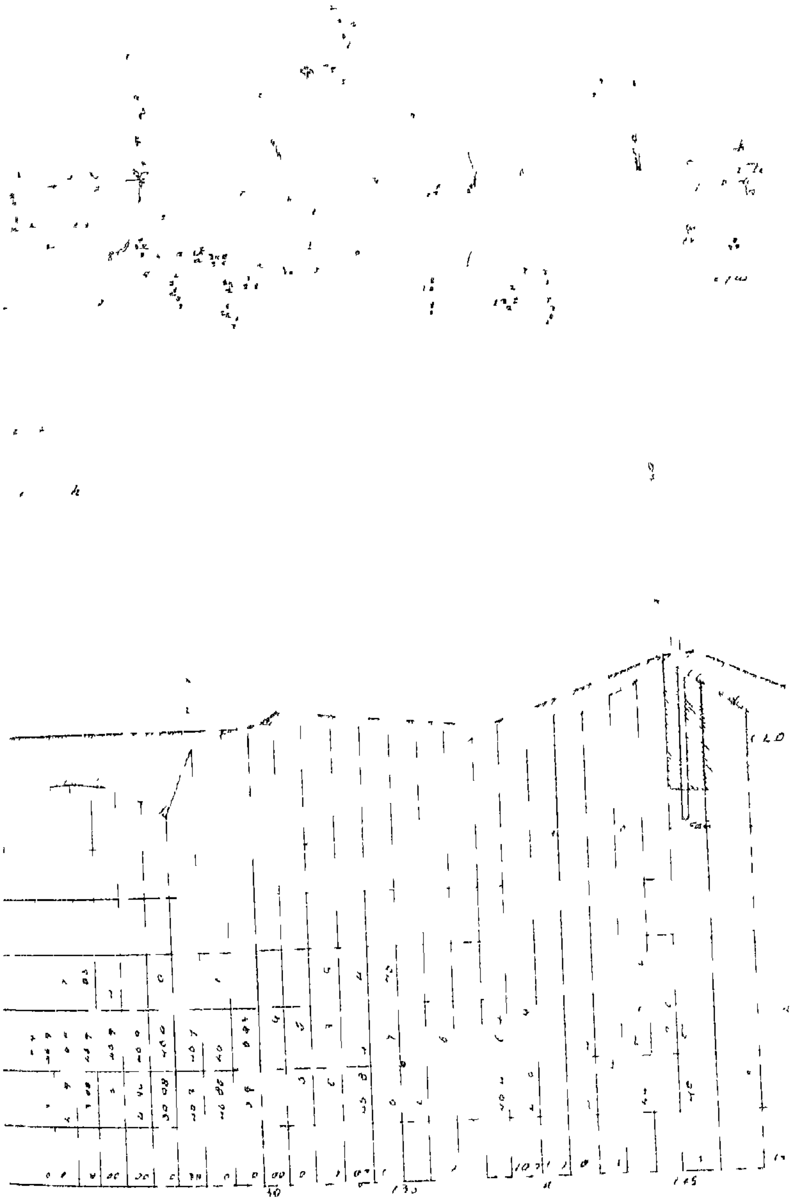


NOW AND FYZABAD ROAD



A higher rate has been assumed for the embanked approaches to the iron bridge and Kookrail nuddee, where the embankment runs up to 25 feet in height, and the earth has to be brought from a distance of 100 to 300 yards

Drain Bridges.—The foundation of piers and abutments to be carried down to good firm soil, and those of the wing walls to the same depth throughout their length.

Curtain walls 2 feet deep to be provided, as shown in the drawings, and a flooring to consist of one brick-on-edge, over two courses of flat bricks.

All the masonry to be of the best kiln burnt brick 12′ × 6′ × 3′, in England bond, set in mortar, consisting of equal parts of choor, lime and soorkhee

All exposed surfaces to be rubbed and pointed with fine mortar between the points.

The filling in of the earthwork behind the wing walls to be done in layers not exceeding 6 inches at a time, and to be well rammed

The other details as in the drawings.

ESTIMATE of EARTH-WORK in a portion of the 1st SECTION of the LUCKNOW and FYZABAD ROAD, *vide* Plan and Specification.

Specification.—The road to be 30 feet wide at the formation surface, with side slopes of 2 to 1, in both cuttings and embankments.

The heights of the several sections are taken to the nearest quarter of a foot, according to the Table below, which is *first* calculated.

No. of chain stump.	Height of section.	Areas of sections.			Mean sectional area calculated from formulæ, 20 or 21 in Vol. I., para. 340.	Length of prismoid.	Cubic contents.	
							Cutting.	Embankment.
30	1·70	58·60	..	..				
31	4·00	..	152·00	..				
32	4·12	..	175·50	..				
33	0·48	15·50	..	..				
		2)74·10	..	..				
		37·05	327·50	..	364·55	100	36,455	
33	5·66	238·62	..	..				
34	4·53	..	175·50	..				
35	3·63	..	..	140·62				
36	5·00	..	200·00	..				
37	5·37	..	..	212·62				
38	4·23	..	163·62	..				
39	3·32	..	..	118·56				
40	3·49	..	129·50	..				
41	0·00	0·00	..	..				
			668·62 4	471·80 2				
		238·62	2674·48	943·60	3856·70 3	100	..	1,28,557
41	1·68	58·60	..	..				
42	2·21	..	77·58	..				
43	3·74	..	140·62	..				
Carried forward, ..		58·60	218·20	..	..	..	36,455	1,28,557

No of chain stamp.	Height of section.	Areas of sections.			Mean sectional area calculated from formulæ, 20 or 21 in Vol I., para. 310.	Length of prismoid.	Cubic contents.	
							Cutting.	Embankment.
Brought forward, ..		58·60	218·20	..	...	..	36,455	1,28,557
44	1·98	..	68·00	..				
45	1·66	..	58·60	..				
46	0·00	0·00	..	..				
		2)58·60	..	..				
		29·30	314·80	..	374·10	100	37,410	
46	0·00	0·00	..	..				
47	3·93	..	152·00	..				
48	4·44	..	..	175·50				
49	1·74	..	58·60	..				
50	1·10	32·00	..	..				
			210·60 4	175·50 2				
		32·00	842·40	351·00	1225·40 3	100	..	40,847
50	0·00	0·00	..	..				
51	2·11	..	68·00	..				
52	2·70	..	..	97·57				
53	0·34	..	7·62	..				
54	2·57	.	..	87·50				
55	1·03	..	32·00	..				
56	0·00	0·00	..	..				
			107·62 4	185·07 2				
		0·00	430·48	370·14	800·62 3	100	26,687	
56	1·47	49·50	..	..				
57	1·45	..	49·50	..				
58	1·64	..	..	49·50				
59	2·22	..	77·58	..				
60	2·20	..	..	77·58				
61	1·88	..	68·00	..				
Carried forward, ..		49·50	195·08	127·08	..	..	1,00,552	1,69,404

No. of chain stump.	Height of section.	Areas of sections.			Mean sectional area calculated from formulæ, 20 or 21 in Vol. I. para. 310.	Length of prismoid.	Cubic contents	
							Cutting.	Embankment
Brought forward, ..		49·50	105·08	127·08	...	..	1,00,552	1,69,404
62	3·27	..	..	118·56				
63	2·17	..	77·58	..				
64	6·60	..	..	279·50				
65	2·37	..	77·58	..				
66	3·57	..	..	129·50				
67	4·02	..	152·00	..				
68	6·11	..	..	252·00				
69	4·05	..	152·00	..				
70	3·62	..	..	129·50				
71	4·31	..	163·62	..				
72	2·67	..	..	97·57				
73	2·17	..	77·58	..				
74	2·10	..	..	68·00				
75	2·47	..	87·50	..				
76	1·28	..	..	40·60				
77	0·07	..	..	..				
78	0·00	0·00	..	..				
			982·94 4	1242·31 2				
		49·50	3,931·76	2484·62	$\frac{6165{\cdot}88}{3}$	100	..	2,15,529
					Total,	..	1,00,552	3,84,933

TABLE USED IN THE ABOVE ESTIMATE.

Table of Areas of Cross Sections of a Cutting or Embankment for a Road.—The road to be 30 feet wide at the formation surface, with side slopes of 2 to 1, in both cuttings and embankments. The surface outline of the several sections supposed to be tolerably level, and the sectional areas* calculated by the following formula, $S = 2h\,(b + h)$, where S = area of Section, h = height, and $2\,b$ = breadth of formation surface. Therefore in this particular case, S, $= 2\,h\,(15 + h)$.

Heights of sections, or values of h, in feet.	Areas of sections for the several heights, or values of h.	Heights of sections, or values of h, in feet.	Areas of sections for the several heights, or values of h.	Heights of sections, or values of h in feet.	Areas of sections for the several heights, or values of h.	Heights of sections, or values of h, in feet.	Areas of sections for the several heights, or values of h.
0·25	7·62	3·25	118·56	6·25	265·62	9·25	448·62
0·50	15·50	3·50	129·50	6·50	279·50	9·50	465·50
0·75	23·61	3·75	140·62	6·75	293·62	9·75	482·62
1·00	32·00	4·00	152·00	7·00	308·00	10·00	500·00
1·25	40·60	4·25	163·62	7·25	322·62	10·25	517·62
1·50	49·50	4·50	175·50	7·50	337·50	10·50	535·50
1·75	58·60	4·75	187·62	7·75	352·62	10·75	553·62
2·00	68·00	5·00	200·00	8·00	368·00	11·00	572·00
2·25	77·58	5·25	212·62	8·25	383·62	11·25	590·62
2·50	87·50	5·50	225·50	8·50	399·50	11·50	609·50
2·75	97·57	5·75	238·62	8·75	415·62	11·75	628·62
3·00	108·00	6·00	252·00	9·00	432·00	12·00	648·00

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* It may be noticed that the above sectional areas increase pretty steadily; the increment to each area being nearly constant for each constant increase in height, *where the heights are nearly equal;* but the increments of the areas become greater as the heights increase. For instance, the areas increase at first about 8 or 8½ feet for each increase of ¼ foot of the height, but in the latter end of the Table, the area increments come up to nearly 20 feet for each ¼ foot increase of height.

The following investigation will show how the difference between any two sectional areas may be found, when the difference between the heights is known, and the whole of the areas may be readily written down from these differences, after the first area has been determined from the equation given above.

Let $S = 2h\,(b + h)$ = area of section whose height $= h$, and

$S_1 = 2\,(h + d)\,(b + h + d)$ = area of section whose height $= h + d$, d being the increase of the height.

Then $S_1 - S = 2d\,(2h + b + d)$, where d, b, and h, are known quantities.

Suppose $d = \frac{1}{4}$, the expression for this particular case, becomes $\frac{1}{2}\,(2\,h + 15{\cdot}25) = h + 7{\cdot}625$. It appears then, that if we have determined the area of any section in the above Table, the area of the next section following, may be found by adding to the area of the last section its own height, and the constant quantity 7·625.

CHAPTER XXXVII.

LINING OUT AND CONSTRUCTION.

181. The work on a Road may be executed by contract or by daily labor. The former method is the most economical, but the contractors should be well watched to see that inferior work is not substituted. Otherwise, bad lime and bricks and badly built masonry will be given in the bridges and culverts, and the defects, concealed by plaster ; the foundations will not be dug to the proper depth, and the embankments will not be put together properly, so that unequal settling and bulging and extensive slips will be continually occurring.

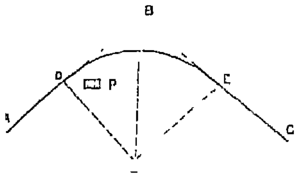
If daily labor be employed, task-work should be exacted from the various gangs, which should have leave to go and be paid up as soon as their task is completed.

Whatever arrangement are made for the execution of the work, the Engineer has, however, first to mark it out.

The straight portions should be laid out by the theodolite—a series of flags being ranged in the proper line by the observer. These are to mark the centre line of the roadway, and therefore the centre line of all the Bridges, Culverts, Embankments and Cuttings. This line should be chained and the sites of the levelling stations in the working plan marked at every 100 feet by wooden pegs. The tops of these pegs should be level with the ground, and the levelling staves for the working levels should be put upon them. Thus they become bench-marks, but in case of their wilful or accidental removal, permanent bench-marks should be established whenever a pucka building or well is passed, or if there are none, solid cubes of masonry, 1 foot each way, can be let into the ground at every 1,000 feet.

182. When there is a change of direction and therefore an angle, the angular point must be rounded off. The curve used is generally a segment of a circle, and as to sweep the curve with a sufficiently longer radius would be conveninent in practice, various methods are used by which an approximation to the curve is laid down sufficiently accurate for all practical purposes.

Curves may be laid out in several ways, a few only of the most useful methods for ordinary practice are given here, including those applicable to Railways and Canals where greater accuracy is required than in the case of Roads.

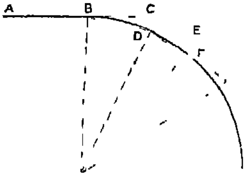


The length of radius to be given to a curve is manifestly indeterminate; for if AB, BC be two portions of a line of a road meeting in B, and it be required to unite them by a circular arc DE, we have by plane trigonometry, DB = DO tan DOB, and since DOB is constant, DB varies as DO; we may therefore either fix the point D and its corresponding point E in the other lines, and find the radius DO by the above equation; or we may assume the length of the radius DO, and thus determine the length of the tangent DB, that is, the distance of D from the intersection B of the two lines.

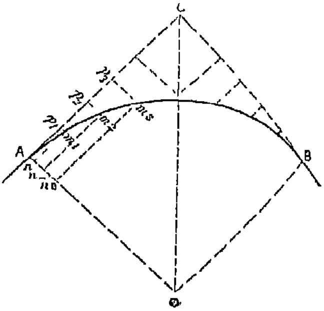
In practice, the first method will generally be necessary; for if any obstruction P, as a well or house, be situated near the line, the commencement of the arc must be taken so that P may be entirely within or without the curve. Again, if there be no features of the ground to determine the question, as often happens in India, from the open nature of the country, a good method will be to fix the point D at some convenient distance from A the commencement of the road, with reference to the division of the road into miles, furlongs, &c., remembering however that the radius thus determined should never be less than 1 mile, and that *ceteris paribus*, the greater the radius the better the road.

The number of chords must depend on the amount of curvature; the fewer chords there are, the less trouble there will be in laying out the curve, while on the other hand they must not be so long as to have any sensible inclination to one another. The versed sine of half the angle subtended by the chord at the centre, gives the greatest deviation of the chord from the arc and by finding this versed sine for different numbers of chords, the Engineer will, generally, after two or three trials, be enabled to fix their number.

183. *Methods of laying out the curve—1st method.—Centre invisible, no angular instrument required.*—Find the length of the the sine of 1° to the given radius, and lay off this distance in continuation on the strait line as from B to C, and from the point thus obtained, lay off at right angles the versed sine to the same angle and radius. The first point D in the curve is thus fixed and by producing the chord BD (= 2 sin 30′ × radius) to a distance DE (= BD cos 1°) and from the point E setting off at right angles EF = BD sin 1°, a second point is thus obtained. By continuing to produce the last chord in a similar manner and setting off the off-set, the remaining points are established



2nd Method.—Same conditions as 1st.—Sometimes the ground without the curve, only, is adapted for chain measurements. In which case, when the curve is not a long one, *i. e.*, does not exceed say one-quarter of its radius, the following method may be found useful. Lay off equal distances Ap_1, $p_1 p_2$, $p_2 p_3$, &c., from A along AC_1 and perpendicular off-sets $p_1 m_1$, $p_2 m_2$, &c., the points $m_1 m_2$, &c., fixing the curve.



To find these off-sets.

$$p_1 m_1 = Ap_1 \tan CAm_1$$

$$p_2 m_2 = 2^2 \times p_1 m_1$$

$$p_n m_n = n^2 \times p_1 m_1$$

For draw $m_1 n_1$, $m_2 n_2$, &c., perpendicular to AO

$$\text{Then } m_1 n_1^2 = Ap_1^2 = An_1 (2r - An_1)$$

$$= An_1 \times 2r \text{ nearly, since } An_1 \text{ is very small}$$

compared with r

$$= p_1 m_1 \times 2r$$

$$m_2 n_2^2 = Ap_2^2 = 2^2 Ap_1^2 = An_2 \times 2r \text{ nearly}$$

$$= p_2\, m_2 \times 2r$$

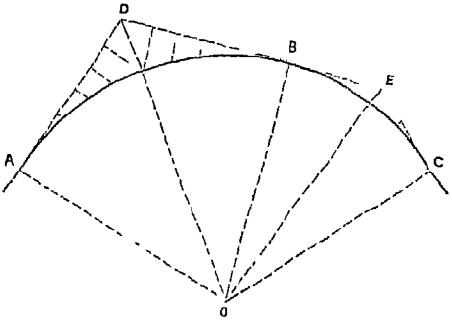
$$\therefore p_2\, m_2 : p_1\, m_1 :: 2^2\, Ap_1^2 : Ap_1^2$$

$$\text{or } p_2\, m_2 = 2^2\, p_1\, m_1$$

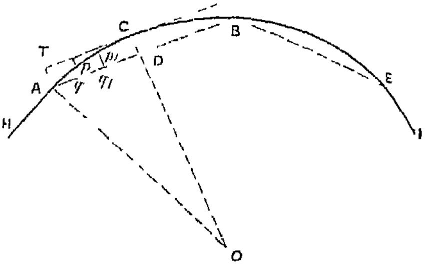
$$\text{similarly, } p_3\, m_3 = 3^2\, p_1\, m_1$$

$$\&c. = \&c.$$

Case II.—By the same method to lay out the curve when it is a long one.—In a long curve, the tangents, if prolonged to their point of meeting, would necessarily fall at a great distance from the curve, thus giving an inconvenient length to the off-sets which in practice should never exceed two chains. To remedy this inconvenience, the curve must be divided into two or more parts, by introducing one or more additional tangents, and thus the off-sets may be confined within their proper limits. In the annexed figure the curve AC is divided into two unequal parts at B; at which point the tangent DBE is introduced to meet the tangents AD, CE in D and E. The tangent AD must first be measured to an extent not exceeding one-eighth of the radius AO. Then, in the right-angled triangle ADO; AO, DO are given, from which the angle ADO can be found; this angle, being doubled, gives the angle ADB which determines the direction of the tangent DBE. If no angular instrument be at hand to lay off this angle, the length of CE can be calculated, and by measuring off the distance CE, the point E will be obtained, and by joining D and E, the tangent DBE. This done, the off-sets to the curve may be laid off as in the last case, the order of off-sets being inverted in DB and again in BE.



3rd Method—Same conditions as first.—Sometimes it may be most convenient to lay out the curve by off-sets from its chord or chords, where obstructions, on its convex side, prevent the use of the preceding method. Let ACB, be a portion, or the whole, of a railway curve; HA, a tangent at its commencement; TC, a tangent to its middle point C. Take if possible the chord AB, an even number of chains; find the successive off-sets to the radius AO and the tangent TC (= AD = one-half AB) the last off-set TA will be = CD; from CD subtract the successive off-sets, and the remainders will be the off-sets p_1 q_1 &c., which must be set off in an inverted order from A to D, and their order must be again inverted in setting them of from D to B. If the curve be not yet completed, the operation may be continued by taking other chords, as BE.*



4th Method.—Centre visible and accessible, no angular instrument required.—This method may sometimes be used with advantage especially for curves of large radii. Find the centre of the curve by the intersections of the perpendiculars to the tangents at the points of contact; place a signal-staff at that intersection, and also at the intersection of the straight lines produced. Divide these lines into any convenient number of equal parts, and set off at each, in the direction of the centre, a distance = $\sqrt{r^2 + d^2} - r$, r being the radius of the curve, and d the distance from the point of contact to the point on the straight line.

184. *5th Method.—Centre visible and accessible, angular instrument necessary.*—Where the curve is quick and the ground over which it passes is hilly, but at the same time is commanded from the points of contact and centre, this method is attended with great advantages, inasmuch as the points are established independently of each other, and are free from all error which may arise (and which in the previous method must be allowed for) from the sloping of the ground. This and the succeeding two are the simplest methods of all, as they require no calculation or measurement of off-sets. They depend on the well known properties of the circle, that the angle contained by a tangent and a chord is equal to the angle in the alternate segment, and the angle at the centre is double of that at the circumference. The appropriate radius having been selected, the angle which a chord, of about the length which it is required to have the points apart, would subtend at the circumference (*i. e.*, the angle in the alternate seg-

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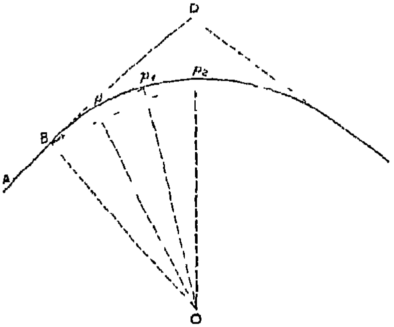
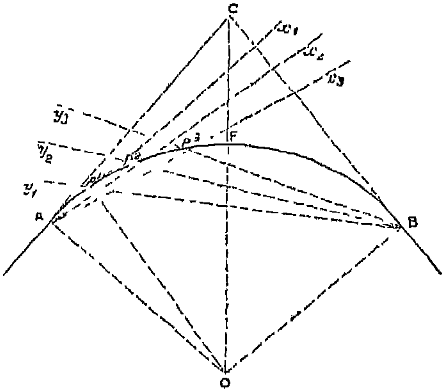
* It will be seen that the tangent TC, is not used in the operation further than to explain the nature of the method of obtaining the off-sets.

ment) is computed from the formula, sine of the angle $= \frac{d \times \textit{rad} \text{ of tables}}{r^2}$, where $d =$ length of chord, and $r =$ radius of curve: thus supposing $r =$ 20 chains, the angle which a chord of 100 feet would subtend would be 2° 10′ 15″; with an ordinary theodolite this angle could only be laid off approximately; an angle of 2° would therefore be adopted, the points due to it being *92·13 feet apart.* This being chosen then as the angle, two theodolites would be set up, one at B the other at O, that at B having its telescope directed on D, and that at O on B, and having clamped their lower plates, the points in the curve will be obtained by the intersection of the arcs formed by moving them through 2° and 4° respectively; for the angle DB $p =$ angle in alternate segment of the circle $=$ one half the angle at the centre BOp. An assistant must of course move by signal a flag-staff until it is intersected by both theodolites, when he will put down a picket to finally mark the spot.



6th Method.—Centre invisible, angular instrument required.—The points in the curve in this method are fixed by intersections from the points of contact of the tangents; first find the angle ACB, suppose it to be $2a$,



then AOC $= 90°-\alpha$, and if the required curve is to be composed of n chords, and Ap_1 is the first of these, $p_1\,p_2$ the second, &c.

$$\text{Then } \angle\ CAp_1 = \frac{90°-\alpha}{n}$$

$$\text{and } \angle\ CBp_1 = (90°-\alpha)\,\frac{n-1}{n}$$

if therefore a flag-staff be moved until it comes into the intersection p_1 of Ax_1 and By_1, p_1 will be a point in the curve.

$$\text{Similarly } \angle\ CA\,p_2 = 2\,\frac{90-\alpha}{n}$$

$$\angle\ CBp_2 = (90-\alpha)\frac{n-2}{n}$$

and so on.

185. *7th Method.—Same conditions as 6th.*—It will often happen that the services of a second person capable of using the theodolite are not available, in which case the above method cannot be applied; the curve must then be laid out by theodolite and chain. Calculate the lengths of the chord Ap_1, Ap_2, Ap_3, AF, (see last *fig.*,) lay off banderoles along the lines Ax_1, Ax_2, &c., (the angles CAx_1, CAx_2 &c., being successively β, 2 β, 3 β, &c, and β being found as already explained,) and measure the chords along them. Proceed similarly from the point B. The point F the centre of the curve should of course coincide with the same point as measured from A; if any small difference exist, the mean of the two points should be taken. To find the lengths of chords

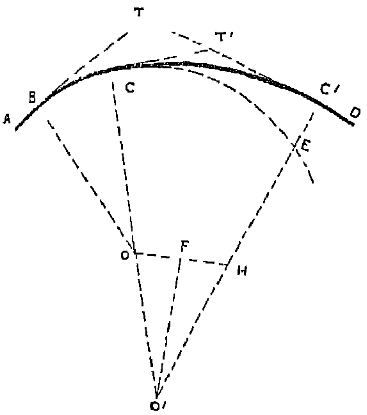
$$Ap_1 = 2\ \sin\ \frac{AOp_1}{2}$$

$$Ap_2 = 2\ \sin AO\,p_1$$

$$\&c. = \&c.$$

This method has the disadvantage of requiring a separate calculation for each chord, but this will not be of consequence when the number is small. It possesses also the further disadvantage that an error made in measuring the length of any chord will not be detected; on the other hand, any error in one chord will not affect the accuracy of the rest, as would be the case in many of the methods ordinarily employed.

186. *The Compound Curve*, consists of two, three or more portions of arcs of different radii, and is adopted where the line is required to pass through given points to avoid obstructions, or where a principal station or terminus is required.



187. *Case I.—To find the radius of the compound curve, the starting point and one radius being given.*—From the given point B in the tangent AB, draw the given radius BO perpendicular to AB ; and draw the curve to some point C, where it is found convenient to change the radius; draw the radius OC, and perpendicular thereto draw CT′, meeting the tangent DT in T′; make T′C′ = T′C, and from C′ draw C′O′ at right angles to TC′, meeting CO, prolonged, if necessary, in O′; then O′ is the centre of the arc CC′ of the curve, conformable to the nature of tangents.

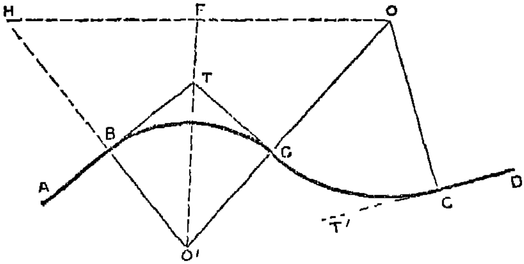
Case II.—One of the two radii of the compound curve, and its starting and closing points being given, to find the other radius.

Let AB, C′D be the tangents, B and C′ the starting and closing points of the curve. Draw the perpendiculars BO = C′H = given radius, to the tangents ; join OH, and bisect it in F ; draw FO′ perpendicular to OH, meeting C′H prolonged in O′; join OO′ and prolong it till OC = C′H: then the points O, O′, are the centres of the arcs BC, CC′, which constitute the curve, O′C = O′C′ being the radius required.

188. *The Serpentine Curve* is used in railways when obstructions or some other cause render its adoption preferable; it consists of two circular arcs of different or the same radii, having their convex sides turned in opposite directions, like the letter S, whence it is sometimes called the S curve; the two portions of the curve have a common normal at their point of junction, and therefore a common tangent at the same point. This curve affords the most easy means of joining two parallel, or nearly parallel, portions of a line of railway.

Case I.—One radius and its tangential point being given, to find the other radius and tangential point of the Serpentine Curve.

From the given tangential point C, draw the radius CO perpendicular to the tangent CD, and draw the curve CG to some point G where it is found convenient that it should have its point of contrary flexure; through OG draw the normal OGO′; from G draw GT at right angles to OGO′ to meet the tangent AT; make TB = TG; and draw BO′ perpendicular to



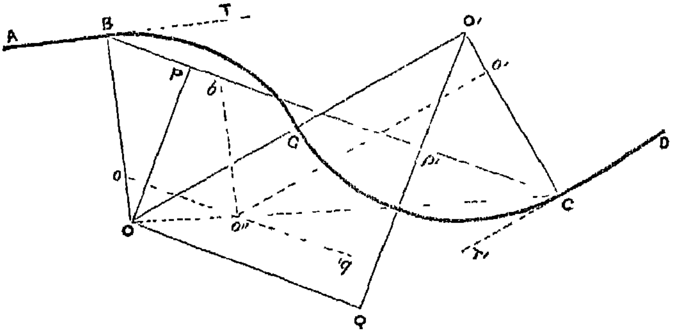
AT, meeting OGO′ in O′; then O′ is the centre, and O′B = OG is the radius of the curve BG, as is evident from the nature of tangents.

Case II.—When the tangential points and one of the radii are given, to find the other radius.

From the given tangential points C and B draw CO, BH respectively, perpendicular to the tangents CD and BA, and equal to the given radius; join OH and bisect it in F; draw FO′ at right angles to OH, meeting HB prolonged in O′; and join OO′, meeting O′G = O′B; then O is the centre, and O′B = O′G is the radius of the portion BG of the curve, as required.

Case III.—When the two portions have the same radius, to determine that radius, the tangential points and their distance being given.

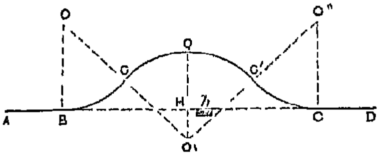
Let AB, CD be the tangents, B and C the given tangential points, and BC the given distance, draw Bo = Co' respectively, perpendicular to AB



CD and of any convenient length; through o, parallel to BC draw $o\,q$ indefinitely; with the compasses apply $o'o'' = 2Co' = 2Bo$; through C, o''

draw $Co''O$, meeting BO prolonged in O; and through O, parallel to $o''o'$, draw O, O′, meeting Co' prolonged in O′; then O, O′ are the centres, and OB and O′C are the equal radii of the serpentine curve BGC, the common normal of the portions BG, GC of the curve, being $OGO' = 2BO = 2CO'$.

189. *Curve of Deviation.*—In some cases it may be necessary to make a given deviation from a straight line of railway, so that the works may avoid a building or other obstruction situated on or near it; this is done by means of three curves as follows:—Let ABCD be a straight portion of the railway, h a building or other obstruction on the line. Take HQ of a sufficient length for a deviation, *that* the line *may avoid* the object at h; and through Q draw a curve GQG′ of radius QO′ equal to, or greater than one mile. Draw also two curves BG, G′C, of like radius, to the first curve at G and G′, and the line at B and C; then the lines OO′ and O′O″ joining the centres of the curves, will pass through their contrary points of flexure at G and G′. Put r = common radius $OB = O'Q = O''C$, and d = required deviation = HQ; then $BH = HC = \sqrt{d(4r-d)}$; and the four equal chords BG, CG, &c., are each equal to $\sqrt{dr}$.



Having given these various methods of determining the radii and common normals, indicating the positions of the tangent points of the parts of Compound, Serpentine and Deviation curves; the manner of laying out the curves themselves by the previous methods, according to circumstances, will be readily seen, recollecting that when junction point of curves of different radii occur to commence the operation afresh, by using the radii and tangent of the respective portions of the curve.

190. CONSTRUCTION.—The construction of the *Earthwork* has already been treated of in the section of that name.

In crossing a *swamp* or *bog*, the great object is to drain it thoroughly. An open drain should be cut on each side of the proposed Roadway and parallel to it, the two being connected by cross drains, and from these other drains must be taken to the natural water-courses. If attempts at draining fail, the road may be boldly carried across the bog, but peculiar materials must be used. It is of no use throwing down bricks, stones, clay, and other heavy material, under the idea that an embankment will be raised up *somehow*, for they will sink in and disappear. Drainage must be carried as far as possible, the bearing surface distributed as widely and evenly as possible, by means of fascines and hurdles, and the lightest materials used for the embankment itself, so that in fact it may float on the surface of the bog instead of sinking into it. It was in this way that George Stephenson carried the Liverpool and Manchester Railway over Chat Moss, after the contractor had given it up in despair.

191. *Metalling.*—Wooden block paving, plank roads, asphalte paving, stone block paving, are rarely if ever used in this country. In general we have to deal with the following sorts—Broken stone or Macadamized Roads, Kunkur, Brick, or Moorum metalling.

Whatever be the metalling used, the great requisite is that it should rest on an unyielding foundation; the embankment must therefore be well consolidated before the metal be laid on, and a thickness of not less than 6 inches of consolidated metalling allowed to distribute the pressure evenly, as well as to stand wear and tear.

For the first, the proper kinds of stone have already been pointed out. The stones should be broken by a hammer into rough cubes that will pass through a 2½ inch ring; the surface of the bed should be prepared to its proper form and the stone laid down in layers of 4 inches thick, which should be successively thrown open to traffic until each layer is consolidated before another is laid down. Not less than two layers will be required, and three should be used where the traffic is heavy. A little gravel or such like material may be used to bind the upper surface more effectually, but it is not essential. Heavy rollers may also be used for the same purpose similar to those described further on. A very good one may be made of sheet iron packed with brick, and drawn by several pairs of bullocks.

For *kunkur* roads the material should also be laid down in layers 4½ inches thick. Two layers will generally be sufficient for an Indian Road, (except on first class roads, where three will be necessary), forming a total thickness of 9 inches of consolidated metalling, and they may be consolidated in two successive seasons. The lower layer should consist of the block kunkur, (where procurable,) and may be made of pieces 4½ inches in diameter; this will form a rough surface, and will act as a foundation to the upper layer, which should consist of small kunkur washed and screened. Each layer must be consolidated with heavy wooden rammers while drenched with water. On this work being properly done depends the goodness of the road. It is generally done thus: three rows of men with rammers standing close together follow each other at an interval of some 6 feet apart from row to row. The kunkur should have three rammings. 1st, when dry; 2nd, when wet; 3rd, when drenched with water. The men should be splashed from head to foot, or the supply of water has been deficient and the work will be spoilt. If there are $4\frac{1}{2}$ inches of kunkur at the centre, they should be beaten to 3 inches; 3 inches at sides should be beaten to 2 inches. This is when the road bed is made horizontal. Sometimes, however, the road bed receives its proper shape, and the kunkur is spread of an uniform thickness as in the case of stone metalling. The kunkur should, when finished, be as smooth and uniform as a stone pavement, and must then be left to dry before any traffic is allowed on it.

Where kunkur is scarce and dear, the lower layer of metalling may be formed of pieces of hard brick.

Brick Roads.—When the bricks are made from nearly pure clay they form a good metal; but if sand predominates, the bricks are friable and quickly pulverize. The contents of the whole kiln should be brought into use; the *jhama*, or vitrified portions, being used for the foundation, and the *peela*, or underburnt, mixed with the other brick will cause it to bind.

192. The following notes on Road Metalling in the Bombay Presidency refer to *Moorum Roads*.

Whenever our funds will allow, the moorum is spread in a layer of 12 inches, with a rubble stone bottoming over the sub-soil, and forms a roadway perfectly capable of accommodating the traffic for the first few years. As the traffic increases, the road crust or surface loses its spongy and porous nature and becomes more tough and consolidated with each succeeding year; but we also become aware, as our road gets into use, of a great difference in strength in the several portions of the line, owing to the varying character of the moorum. Our attention must now be turned to the elimination of all such weak and bad portions of the line. New moorum pits must be searched for, and failing their discovery, the lead from the good pits must be extended from either side of these places, so as to shut them out, and bring the strength of the line up to nearly an uniform level throughout.

In many places where the moorum spread has been of a superior quality, and the crust of the road is sufficiently strong to carry with safety a thin coating of metal, it would be advisable to substitute broken stone for moorum, in the annual repairs, as at the same expenditure, stone is more durable than moorum. A strip of metal, 12 feet broad by about 2 inches deep, laid in the centre of the roadway during the monsoon, would find a bed for itself on the moorum surface. This would give about 2 cubic feet of metal to the running foot of road, instead of $4\frac{1}{2}$ cubic feet of moorum, that would be required for repairing the roadway, 18 feet wide and 3 inches deep with this latter. But as 2 cubic feet of metal are fully equal in wear to 5 cubic feet of moorum, there is a saving in using stone, besides providing a road properly passable during the rains. The cubic foot of second-class metal would cost Rs. 6, and an outlay of Rs. 12 on metal would give results equal to Rs. 15 on moorum of the average quality.

193. The following notes upon the Rollers used for consolidating road metalling will also be found very useful :—

The rollers usually employed on moorum roads are made of stone, such as hard trap; they are in length about 4 feet, and 2 feet diameter, weighing say 1 ton each, or 47 lbs. to the inch of bearing surface. To ascertain whether the effect of these rollers is sufficient to give us a surface hard enough to carry the traffic without injury, we must compare the compression exercised by them with that of the wheels of a laden cart, which carry in all probability the greatest weight per inch of bearing surface of any traffic using a road. Our rolling operations will evidently be of little efficacy unless they provide a stratum sufficiently tough to resist the action of the cart-wheels, or in other words the weight of the rollers should be, inch for inch of bearing surface, at least equal to that on the cart-wheels. We may assume that each laden cart has a total weight of at least half a ton, including the cart itself; this gives 5 cwts on each wheel, and taking the tire at 2 inches broad, a pressure is produced of 280 lbs. per bearing inch. This is six times the pressure of our stone rollers, and leads to the belief that there is little efficacy in rolling with such light weights. It is evident that if it be possible to procure rollers with a bearing weight of 280 lbs. per inch or upwards, our labors would be much lightened. These views are confirmed by experience, as we find that with light stone rollers, the upper crust or surface is only made smooth, and below this is material in an unconsolidated state; the roadway being consequently soon cut through and broken up by the traffic. With metal, these rollers are entirely useless; wherever they are now in use, they should be got rid of as soon as possible and others substituted, which permit of being weighted up with stone boxes and in other ways.

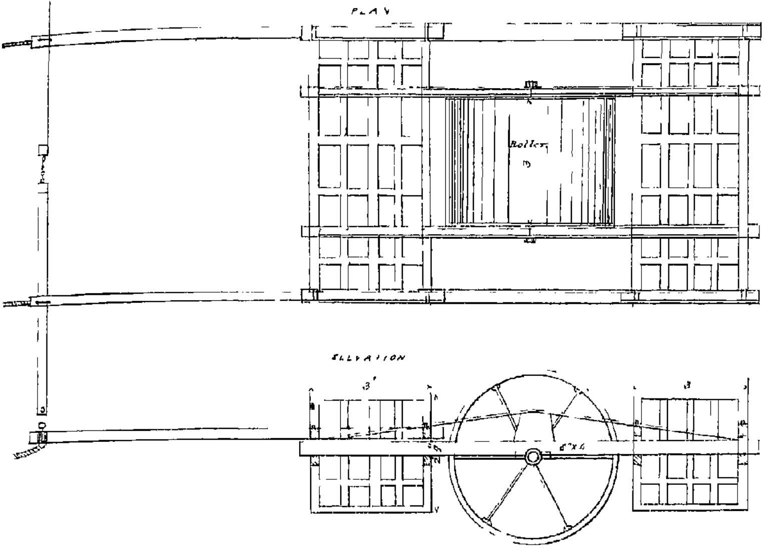
Before however proceeding to describe the superior kinds of rollers, it will be as well to show what can be done with the present stone rollers, so as to make them in some degree efficacious, at least for the consolidation of moorum and similar materials, it being always borne in mind that as near an approach as possible should be made with these machines to the weight on a cart-wheel. Instead of being made cylindrical, they should be either barrel-shaped or bevelled. The effect of this shape is that the bearing surface is reduced to about one-third of its former extent and the weight per inch is trebled, being now 141 lbs., or half that on a cart-wheel. These rollers can be made at the same price as the usual cylindrical ones, and are easier to turn and lighter in draught than these latter. They should more especially be made of the hardest stone procurable. There is one point about the barrel-shaped roller which appears to give it an advantage over all other shapes. It is evident that with each successive rolling as the road becomes harder, the bearing surface of the roller decreases and the compressive effect is increased at the time it is most wanted. Iron rollers should be cast in this form as being probably a more scientific shape than any other. Any slight inverts or cusps caused by this roller would disappear under repeated rollings, and by the wear of the traffic.

We now come to the consideration of those Rollers which permit of being weighted up, and for this purpose a stout iron axle running through the body of the roller is

PLATE XXXIX

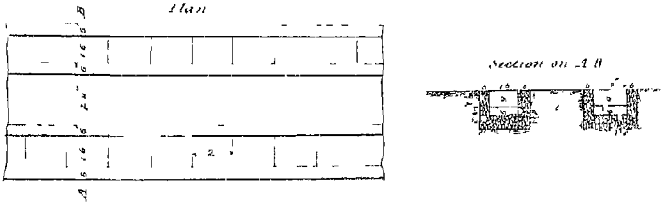
ROAD METALLING.

Iron Roller with Counterpoise Stone Boxes Drawn by 4 Bullocks abreast



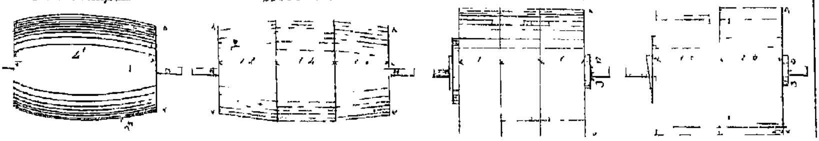
Scale 1 1

Stone Track



Scale 8 = 1

Stone Rollers



Barrel Shaped

Bevelled

Formed of 2 or 3 Stone Wheels

necessary. We are limited, consequently, by this consideration to the common English iron roller, and a country roller made up piece-meal with stone wheels similar to those used in grinding chunam. Drawings of these two are given, and a frame work with counterpoise stone boxes shown with the iron roller; the same frame-work does for the stone roller and is not therefore shown with it. These stone wheel rollers cost about Rs. 60 per cent. more than those cylindrically shaped, say Rs. 40 and 25, respectively. Their weight is 3,780 lbs. or 105 lbs. to the inch bearing. One ton can be added to this by means of the framework and stone boxes, which gives 167 lbs. per inch bearing. We are still however far off the weight necessary for rolling metal, for which the iron rollers are most effective. The compressive effect of these stone wheel rollers might be greatly increased by making them barrel-shaped or bevelled, but their construction would not permit of this.

The width of the English rollers is 3 feet, and diameter 4 feet, and the weight about 2 tons. The stone boxes and framework would give another ton; and if the interior be boxed up and filled with scrap-iron, such as unserviceable pickaxe heads, &c., of which every Executive Engineer must possess a quantity, we should have a total weight of say 5 tons, or 311 lbs. per inch bearing. These rollers may therefore be depended on for consolidating both moorum and metal. They might be made much heavier by filling the interior with lead, but it seems doubtful whether any corresponding advantage would be gained to counterbalance the increased difficulty of draught.

The stone boxes are useful as counterpoises, which is effected by removing a few stones from one box to the other; as for instance, on an ascent a certain weight removed from the rear to the front box would much facilitate the draught of the bullocks, according to a well known law.

In all the foregoing calculations, it has been assumed that all the rollers insist or stand on an area proportional to their length only; this is not strictly true, and is only the case where the surface of the roadway is perfectly hard, and in practice the area is proportional to the diameter of the roller. This is an important fact, as thereby the effect of the larger rollers is considerably reduced. To recapitulate then, and to exhibit the effective power of each kind of roller after taking all the above into consideration, we have the following results :—

No.	Item.	Weight per inch.	Proportion.
1	Cartwheel, say 4 feet diameter on the average,	280	1·000
2	Iron rollers, weighted up, 4 feet diameter, ..	311	1·117
3	Stone wheel rollers, weighted up, 3 feet diamr.,	223	0·796
4	Bevelled or barrel-shaped rollers, 2 feet diamr.,	282	1·007
5	Cylindrical stone rollers, 2 feet diameter, ..	94	0·336

194. *Maintenance and Repairs.*—Unless arrangements are made for the proper maintenance of a road when finished, it will be better not to waste money in making it. A pucka road in bad repair is almost as bad as no road at all, but with proper supervision and a small but regular expenditure, no extensive repairs ought ever to be required, and the road at all seasons of the year will afford the means of safe and rapid transit.

To keep up a road, an establishment will be required, consisting of gangs of laborers under proper overseers, who should have so many miles of road to look after; and supplies of material for petty repairs to the metalling should be collected and stacked by the road side; not on the space allotted for travellers but on the berm beyond. A consolidated stratum of 3 inches of metal laid as above described on a prefectly hard foundation will bear any work, and last three years under such traffic as that of the Grand Trunk Road. The upper stratum of metal will therefore require renewal every four years; but meanwhile holes and ruts will occur in places which should be carefully repaired as they occur, by filling them in with fresh small kunkur, and ramming them prefectly flush with the rest of the work.

The best time for the annual repairs of a road is at the close of the rainy season, but petty repairs should go on all the year round, and every endeavor made that whatever repairs are required, should not seriously interfere with the traffic, as is too often the case. The side-slopes, tufing, &c., should be attended to as well as the metalling, but they will generally fall under the head of annual repairs.

195. The following Specifications for this kind of work as used in the Allahabad Circle of Public Works, will be found useful:—

Maintenance of road.—The surface of metal, whatever its width, to be always kept free from holes, ruts, and worn-patches, and to be maintained as much as possible with its due central rise of 1 inch per 3 feet transversely, and to its full original width.

Immediately on the appearance of any failure of the surface such petty repair shall be executed as shall restore the portion to its original condition.

The repair shall be commenced always within 36 hours of the first appearance of failure.

In executing such petty repair of metal, the hole, or rut, or patch, shall be cut out to the full depth of the coat of metal in a rectangular form, enclosing the whole of the patch and parallel with the centre of the road; the sides of the excavation shall be sloped off.

Metal of the quality and description specified for annual repairs shall be laid into the hole and properly consolidated; the surface of the new patch when completed, lying perfectly even with the remainder of the road.

The metal for these petty repairs shall be supplied by the Contractor, and he shall be bound to keep up a constant supply of 1,000 cubic feet in each mile of road, to be stored separately from the annual repair metal in such convenient depôts as he may choose for each mile.

The earthen sides and slopes of the road shall be kept even, free from ruts and holes, and generally ranging in height with the surface of the metal.

The side drains and water channels shall be kept open and free for the discharge of water.

The surface of the road generally shall be kept free from accumulations of water.

The road side trees are to be tended and cared for, the lower branches of large trees to be lopped carefully during the months of December and January to the requisite height to admit a free head way for the traffic and no more, but without injuring the trees. All limbs of trees are to be *sawn* off. Young trees to be protected from injury by traffic or cattle in the usual manner with thorns or mud walls, where necessary.

Collection of metal for repairs.—The *kunkur* to be hard, clean, and fit for road metal in every respect, broken to 2-inch gauge, to be sieved and cleaned, so as to be perfectly free from earth and other matters before it is brought to the road side.

The *moorum* to be hard and firm, so as not to be easily crushed under the foot, to be of a sharp gravelly nature, and free of soil; to be sieved at the quarry; meshes of sieve not less than $\frac{3}{16}$ of an inch square.

The *stone* to be hard, of close texture (not friable sandstone,) to be broken to a size to pass through a $3\frac{1}{2}$-inch ring every way for the lower layer, and $1\frac{1}{2}$-inch ring for the upper layer; no round or pebble-shaped stones to be allowed amongst the metal. The stones to be broken clear of the road and slopes, and must be perfectly free of earth or other matters.

The metal to be stacked on the berm, free from the sides and slopes and side drains. No metal to be measured until it has been so stacked.

In measuring the metal collection, the product of the length, breadth, and of $\frac{12}{13}$ of the height, will always be held to be the net cubic contents of the stack.

The metal collection for annual repairs is all to be effected between the 1st November and the 30th April next ensuing.

Consolidation of metal for repairs.—The surface of the old metal is to be scored up with the pick in parallel diagonal lines at 6 inches intervals.

Two parallel mud walls 8 × 6 inches to be formed along the outer edges of the metalling, leaving an interval between them of the full width of the metal, to confine the metal and prevent its spreading under the action of the rammer.

The new metal to be spread upon the old surface closely packed with the hand, the larger pieces below and the smaller above.

The surface of the new metal to be laid with the usual central rise of 1 inch per 3 feet transversely. As a guide to the workmen $5\frac{1}{2}$-inch cubes of wood will be laid at intervals of 16 feet along the centre, and 3-inch cubes along the side of the metalling, the upper surface of which after consolidation must coincide with the tops of the cubes. Care must be taken to bed all the cubes on one horizontal plane.

The metal to be saturated with water and rammed with rammers until thoroughly consolidated, that is, until the wheels of ordinary light vehicles passing over it cease to leave any impression. The surface to be watered for three days after this consolidation has been effected.

Earthwork for repairs of sides and slopes.—The earthen sides and slopes receive periodical repairs simultaneously with the renewal of the coat of metal. All other repairs to them will fall under the head of maintenance.

The repairs consist of making up the sides to a width of 8 feet from the edges of the metal coat and to the full height thereof, with a slight fall to the outside to throw off water; and in filling in all holes and channels in the slopes, and dressing them off evenly.

The earthen sides and slopes are to be repaired immediately after the adjacent portion of metal has been opened for traffic. The clods will be broken down, the surface rammed and smoothly dressed.

Excavations for supply of the necessary earth will in no case be opened within 36 feet of the centre of the road. The Executive Engineer will give special directions in this matter where necessary.

Earthwork.—To include all embankments raised and excavations cut—tanks, hollows, or channels filled, or excavated in any gravel or clay soils, but to exclude excavation for foundations and wells.

One foot vertical lift to be taken as equal to 10 feet horizontal lead. In the case of an embankment, this proportion for lift to be added to the horizontal lead.

In filling an excavation or hollow, the horizontal lead only to be allowed.

The lead to be measured in the case of a road, from the centre of the excavation to the centre of the bank.

In filling a hollow or excavation, from the centre of the cutting to centre of hollow.

In case of tank cutting, &c., from its centre to centre of spoil bank.

If the soil has to be carted, the excavation will be paid for under that head without lead, and the cartage separately at the Schedule rate for that work.

Earthwork shall be measured from sections of the bank to be raised, or hollow or excavation to be filled, or bank or channel to be cut. In the first and third cases, cross sections be shall taken at no greater intervals than 330 feet, and each portion between two sections shall be calculated separately as a pyramidal frustum or from published tables.

In the second case, the hollow or excavation shall be measured before the work is commenced, and the Executive Engineer and Contractor shall agree in writing as to the quantity of work to be done.

If the Contractor commence the work, it shall be evidence that he is satisfied with the measurement proposed by the Executive Engineer.

All embankments shall be raised in successive layers of 1 foot depth, slightly concave at the centre and consolidated.

The side cuttings shall never be made nearer than 10 feet clear from the toe of the slope of the bank, and they shall not be continuous, but shall be broken at intervals of not more than 300 feet, by a block of earth not less than 10 feet wide.

The sides of all side cuttings shall be sloped at the natural slope of the soil.

No kunkur shall be quarried in the side cuttings.

In cuttings for hollow roads the cutting shall always be taken out square to the width of the travelling surface down to the formation level, and the slopes be cut afterwards.

Turfing, grassing, and sodding.—Turfing and grassing slopes and surface with *dhoob* or other grass, or cutting and placing sods.

In turfing and grassing the grass seed may be sown or the roots of dhoob, khus khus, or other grass planted according to orders, and watered until they vegetate, On slopes the seed should be drilled in horizontal lines.

Sodding will only be executed in situations where good strong turf sods can be cut within a mile. The sods are to be cut nearly of a size, and arranged so as entirely to cover the surface.

Sods may be used built as retaining walls to steep slopes; in this case their length, breadth, and thickness must be in the proportion of 6, 3, and 1 inches; they will never be less than 3 inches in thickness, and must be laid in courses alternately header and stretcher; the beds at right angles to the batter; and the successive courses breaking joint with the one below. Each course when laid must be beaten down with large flat rammers so as to pack the sods closely, but without breaking them. The backing of soil must be built up evenly with the retaining wall, course for course.

The rates for sodding will be based on the assumption, that sods can be cut within 300 yards of the work, a charge for extra lead will be allowed, if they be carried more than that distance.

No grassing or sodding will be executed to embankments, or other made earthwork until they have stood one rainy season.

CHAPTER XXXVIII.

HILL ROADS.

196. *Tracing Hill Roads.*—Before commencing the trace of a mountain pass or *ghaut*, the best attainable map of the country should be consulted, and a preliminary and careful inspection of the slopes of the range to be crossed will be necessary, with a view to ascertain the direction and extent of the ravines and water-courses, and the nature of the ground, whether it admits of being cut, or if it is too rocky and precipitous.

If the hills are extremely wooded, the operation becomes more difficult, but native footpaths may often be found, and an inspection of these will show in some measure the nature of the ground, though not altogether, for they generally follow some spur of ground, and so fall into the lower part of the valley soon, and are very steep. They afford, however, useful hints, and after having fixed upon the valley, through which the proposed road should be led, it is advisable always to survey any old road or path which may be found in it: this laid down on paper, will be a good beginning for a rough map of the country, and prove a guide to the direction of the new pass.

The slope at which the road is to be constructed must now be decided upon; this will depend on the purpose for which the road is required, and something on safe halting places. It is not expedient that these should be far apart, but almost all hill ranges in India are feverish within certain limits, and except at particular seasons, people can seldom sleep within four miles of their base without danger. For quick traffic, the slope should in no part be steeper than 1 in 20, and if possible, should be less steep than that. Supposing the general minimum slope is 1 in 30, a great expense might be saved by making portions here and there, at a slope of 1 in 20, for a pair of bullocks could draw a full load for a few yards up a steep slope, though they could not do so for a greater distance. Having ascertained the height to be crossed, and assigned the maximum general rate of slope, multiply one by the other, and the minimum length is the result. Next, try to get a maximum length of hill, in the general direction of the proposed line, and the easiest possible ascent will be obtained.

A valley or ravine extending far into the country to be ascended, or range to be crossed, affords a better hope of a good line of road, than following a spur and attempting to work it out by zig-zags, and moreover has the advantage of every mile being so much in the ultimate direction, while a zig-zag is an expedient for gaining length with reference to the slope only, and without reference to the ultimate progress, and should be avoided whenever the nature of the country affords the advantage above pointed out.

It is difficult to write generally on the other points to be attended to in tracing—viz., fixing the head and foot of a ghaut, the places to cross rivers and streams, and when to change from one valley to another: some of these become fixed points, to which the road must be brought, and it requires considerable care to determine them to the best advantage, and no slight practice to work the slopes into them, without expedients or loss of ground.

Experience in executing a road will be found necessary, to enable the tracer to avoid a great many inconvenient errors, into which he will otherwise generally fall.

An aneroid barometer will be found a great assistance to the tracer, in determining comparative heights, and its portability renders it much superior to the mountain barometer.

197. The following Notes on Hill Road Tracing in Madras, will be found useful:—

Of the two, the labor of tracing a mountain road, is greater than that expended in the actual laying out of the sheer descent of the ghaut itself, but it requires not a little scientific experience to pitch upon a general line for the latter, that will give scope for running a trace at a fixed gradient of 1 in 20, without having recourse to the clumsy expedient of zig-zags. Either a deep ravine or valley should be sought, up whose flank the road may be carried; or a long spur or series of spurs, round and about which it may wind, should be chosen; and where such a formation can be found, a combination of both features is best. Much deliberation and care has to be exercised at the outset, in judging by the eye of the practicability of the site chosen for the descent. Where the jungle is very close a trial trace cannot well be run without great loss of time and useless expenditure of labor; all which is saved by having the ground reconnoitred by an experienced Engineer, who, with the help of the aneroid barometer, can pretty accurately settle the question.

The head of the ghaut is usually a fixed point; and if it is not left open to doubt that it *must* be adopted in any case, the tracer may commence his line, working downwards, wherever his levelling staff carries him; recollecting he must ease off his slope a little when turning corners, and must cross all streams at a dead level. Once he has started, it is impossible to lay down fixed rules for his guidance, and there is frequently an ample field for the display of ingenuity and talent before he reaches the level ground beneath; in truth to pilot his instrument through dense forests, calls for the involuntary application of not a few principles of the inductive philosophy.

For such work, in such a country, it may be imagined the common Spirit Level is eminently unsuited. Weighty to carry, and cumbrous to set up in position, where the operator can barely find room to stand; and where a clear prospect of even a dozen yards in front of him, is not to be obtained without felling the scrub which hinders advance and obstructs the views; its use has been wisely discarded in such ground.

The instrument employed is, what is known as the Gunner's Quadrant, or level for setting mortars at their proper angle, modified a little. The long bar is fitted with sights at either end, and has a universal joint screwed on at its centre.

The quadrant is reversed from the position it occupies in the mortar quadrant; having the arc turned inwards, and the radius outwards towards the tracer. An armature, bearing a small spirit level at its side, and a vernier to read minutes at one end, works on the arc, which to enable the level to be used for tracing either up or down hill without reversion, has an excess arc of some 5° on the upper side of its zero point. Seeing that an angle of 3° corresponds to a slope of 1 in 20, an arc of 90° is considerably in excess of the angular accommodation necessary in tracing roads, and Messrs Elliott, Brothers, might with advantage curtail this over-balancing appendage: they might also put the spirit level in permanent adjustment.

The tracing quadrant is fixed to a light stick, shod with iron, of a length sufficient to bring the pinhole of the sight within easy distance of the eye. The stick should not terminate in a point, or the levels will be vitiated. Its base ought to be about one and a half inches in diameter.

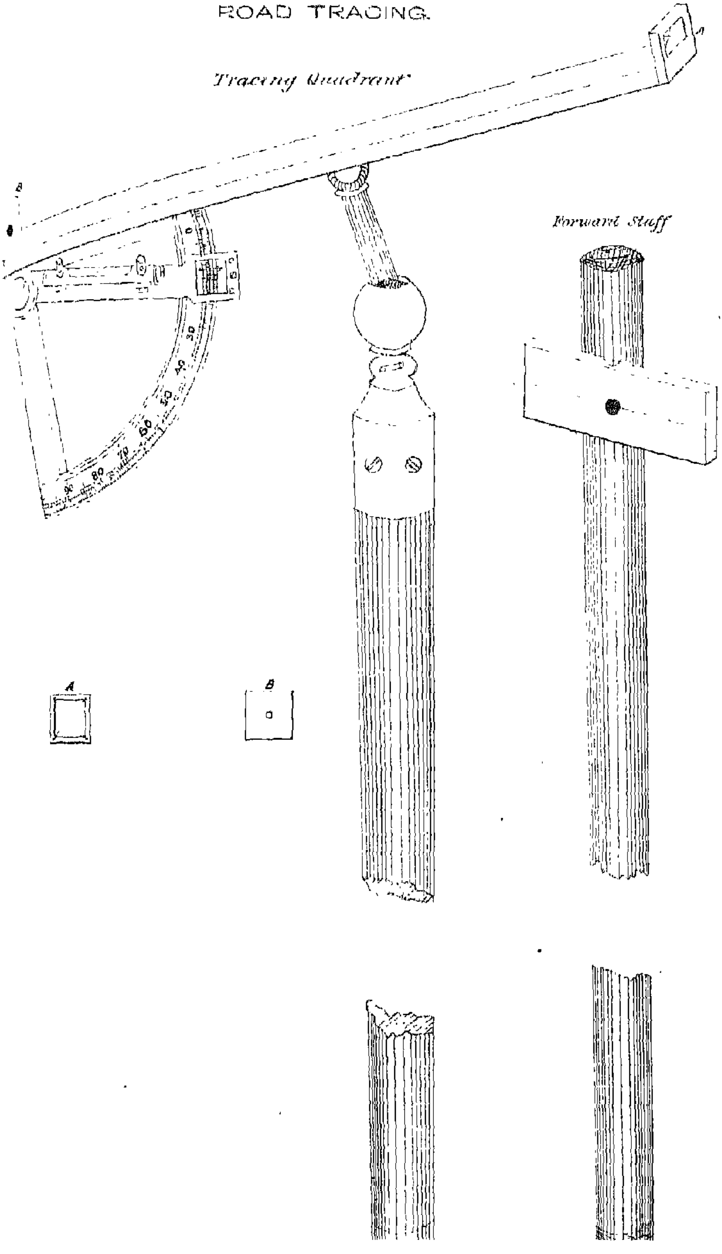
The forward staff is rather longer than the foregoing, but has a fixed vane, painted white, whose centre is exactly the same height from the ground as the pinhole of the quadrant sight. The centre is denoted by a dot in the middle of a black horizontal line.

The tracer holds the instrument in his hand, having adjusted the armature by the scale and vernier, to the angle of inclination suited to the lay of the ground. A slope of 1 in 20, corresponding to 2° 52′, or to within a few minutes of 3°, should be the maximum, except for temporary descent into water-courses, which may be 1 in 12, or 4° 45′. The holder of the forward staff goes on a few yards and is signalled up or down, till the foot of it is resting on the line of the required slope. The tracer has no difficulty in catching the bubble of the level with his eye, at the same moment as he watches the vane of the staff through the pin-hole sight and cross hairs and as soon as properly placed, he orders a peg to be driven at its foot. He then moves up to the peg, and sends the staff bearer forward to take up a fresh position; and so on till the trace is pegged in. A party follows to open out to one yard, and when the line has been inspected by the Executive Engineer and approved of, to 12 feet: next season the road is finished to the full width, with a side drain.

This simple method of tracing is admirably suited to rough undulating country covered with forest, where an ordinary spirit level cannot be easily carried about or set up; and where extreme accuracy is not imperative as in the case of common roads.

PLATE XL.

ROAD TRACING.


Tracing Quadrant

Forward Staff

Even a practised eye cannot lay out a road on the hill side that would not be found to depart widely from the uniform slope proposed, unless the instrument has been in hand all the time ; eye traces as they are termed, should therefore be proscribed, except on flattish ground, where the slavish following of the instrument is apt to lead to the marking of a tortuous line. If a cutting through a saddle or spur has to be made, it is usual to denote its commencement and end, by inserting two pegs instead of one ; and at descents into streams, the same course must be observed. Great care should be exercised that the latter are formed with due regard to facility of passage, for many an excellent road trace is marred by insurmountable difficulties at the steep banks of rivers, or headlong ramps.

The pegs thus laid down are on the centre line of the future road, and when opening the gauge path, the laborers are careful to stretch a strong line from peg to peg ; by means of which the gradient is rigidly worked to. Before excavating, an upper row of temporary pegs, 3 feet higher up the hill side than the centre pegs, is inserted to denote the edge of the cutting in a like manner with the aid of string. If all these precautions are attended to, an even path upwards of a yard wide is speedily formed, and the slopes are preserved for ever. If nothing further is done to it, this path itself is often an immense accommodation to both men and animals ; while it enables the Engineer to see his way much more clearly than if he had to grope through the jungle without so safe a guide. Any improvement in direction which suggests itself, is staked out after a thorough examination of the trace, and it is not seldom that the adoption of a deviation here and there is advisable.

A road, it has been mentioned before, through a hilly district, is more troublesome to trace than the incline of a Ghaut. This is due to the difficulty of determining by the eye alone, how particular features had best be dealt with, and it requires a great deal of care and practice to escape committing mistakes in the choice of gradients, and thereby losing both time and temper from being obliged to do work twice over. As a general rule, the saddles, over which the road must go, are first inspected ; and it often happens that a small depth of cutting at the top will enable them to be crossed without exceeding the limit of 1 in 20 ; then the most suitable sites for bridges are roughly fixed ; and after these observations are taken, the bridle path is levelled in to the *best of the tracer's ability and judgment*. *On moderately flat* ground, when it is certain all the slopes are within 1 in 20, the instrument need not be used, but the line is ranged as straight as possible, the ground to a sufficient width on either side is cleared, and the side ditches are staked out, and excavated at once, enclosing the full width of the road between them.

It has been customary in Madras to widen the 3-feet trace to a width of 12 feet the first season, as doing so permits pack bullocks or even a single cart to pass along. The surface of the road inclines outwards slightly, to let the water run off, and no drain is allowed to be put on the inner side. There is, however, a check or intercepting channel, 18 inches broad and deep, cut some 30 feet above the road, discharging across it at convenient spots.

Experience has shown that a 12 feet road is little injured by the rains.

The objectionable expedient of giving the road surface an inward instead of an outward slope, is, by unskilled persons sometimes resorted to, a method that results in the road being soon cut up and becoming a mere water-course.

During the second season, the building of bridges and culverts used to be begun, and the road was widened to its full dimensions of 18 feet for a district, and 21 to 24 feet for a trunk road.

Everywhere, in side cutting, an inner drain was added to a road wider than 12 feet; but the transverse section of the road surface was as nearly horizontal as possible, half of the drainage falling outwards.

198. *Tunneling.*—When the excavation exceeds a certain depth, it will be cheaper to make a tunnel as a substitute. The amount of excavation will be much less, but the cost of each yard of it will be much greater. Calculation in each case can alone decide at what depth it would be economical to abandon the open excavation, and to commence the tunnel. Sixty feet is an approximate limit in ordinary earth. The necessity for tunnels seldom occurs, however, in the construction of common roads, and they will be more appropriately treated of under the Section RAILWAYS.

199. *Blasting.*—Not only rock, but frozen earth and sometimes very compact clay, are removed by blasting with powder. The holes are drilled by a long steel bar, called a *jumper*, which is raised and let fall on the desired point, and at each stroke turned partially round, so that the cuts cross each other like the rays of a star. The holes are made from 1 to 3 inches in diameter, and from 1 to 4 feet deep. One man can drill in a day 18 inches of a hole, 3 inches in diameter, in rock of average hardness. When water percolates into the hole, it must be dried with oakum and quicklime, and the powder enclosed in a water-proof cartridge. The proper proportion of powder being introduced by a funnel and copper tube (so that none may adhere to the side), a wadding of hay, moss, or dry turf, is placed upon it, and the remainder of the hole is filled with some tamping material. The best, for safety and efficiency, is dried clay. The next best material is the chippings and dust of broken brick moistened slightly while being rammed. An inch or two of the wadding being simply pressed down upon the powder, the filling material is rammed, or "tamped," with a copper rod till it becomes very compact. Through it, passes from the powder to the surface, some means of ignition. A reed filled with priming powder, and ignited by a slow match, is generally used by native workmen. Where it can be obtained, however, the safety fuse should be employed. This has the appearance of a common tarred rope, and is so prepared that the length of it, which will burn any given time, can be exactly known, so that no premature explosion need be feared.

The proper charge of powder, and the direction of the holes, are very important, both for efficiency and economy. The proper regulator of the charge is the length of "*the line of least resistance,*" *i. e.*, the shortest distance from the bulk of the powder to the outside of the rock, which should *not* be in the direction of the hole bored. To produce similar proportional results in different blasts, the charge must be as the *cubes* of the respective lines of least resistance. Thus, if four ounces of powder will just suffice to blast a mass of rock when the L. L. R. is 2 feet, the charge for another in which it was 3 feet, would be given by the proportion $2^3 : 4 :: 3^3 : 13\frac{1}{2}$ ounces. The *absolute* amount of powder required depends on the strength of the powder and the tenacity of the rock, and should be determined in every case by direct experiment.

On a high face of rock a system of undermining may be usefully employed, by blowing out a mass below, and removing the remaining overhanging portion by crowbars, wedges, &c.

No loud report should be heard, nor stones be thrown out. The best effect is produced when the report is trifling, but when the mass is lifted, and thoroughly fractured, without the projection of fragments. If the rock be only shaken by a blast, and not moved outwardly, a second charge in the same hole will be very effective.

The safety of blasting operations may be greatly increased by applying galvanism to the ignition of the powder, which can then be effected at any distance. By its aid a row of blasts can be exploded simultaneously, by which their effective power is greatly increased.

200. The following account of Blasting operations on the Lahore and Peshawur Road will be found interesting :—

> The old road from Attock to Peshawur, after crossing the Indus, runs for above three miles through a range of low but rocky and precipitous hills. This part of it is exceedingly narrow in many places, little over 10 feet, and some of the principal ascents are as steep as 1 in 8. It is known as the Gidar Galli pass.
>
> The right bank of the Cabul river was selected for the new line. The only great obstruction on it was a cliff of limestone rock, near the village of Khoond, that jutted abruptly into the river. The height of this cliff above the cold weather level of the Cabul river is 145 feet. Its total length on the river face is 1,033 feet. Of this length only 285 feet presented any extraordinary difficulty ; the slope of the remainder of the hill, taken at right angles to the river face, was comparatively gentle, being in some places nearly 1½ of base to 1 of height.
>
> The following account refers merely to the plan adopted for removing the precipitous cliff of limestone rock, 285 feet in length.
>
> Two sets of sections are given in the accompanying sheet of drawing. The first set show the section of the hill when work was commenced, and the present section ; the second set show the section of the hill before and after the explosion.
>
> On the 3rd June, 1850, the level of the road having been approximately fixed, the first and second Companies of Sappers commenced work by opening a path round the hill on the intended level ; when the path being finished, the Officer Commanding the Sapper Companies, in the absence of a liberal supply of blasting powder, applied his men at the top of the hill to cut it down by manual labor, assisted by small blasts of powder when the rock would not yield to ordinary tools.

Under this arrangement the execution of the work would have required an extravagant length of line, and the economy of the measure was doubtful; it was consequently determined to break up the cliff by four large charges of powder, placed as shown in the drawing. It was expected that these mines would throw a considerable portion of the upper edge of the cliff into the river, and that what remained would be so broken up as to be easily wheeled over the edge of the road without further use of powder.

By the beginning of November, 1850, the two horizontal galleries into the face of the cliff were fairly commenced. No. 2, measuring with returns, 100·5 feet in length, was completed on the 25th of January, 1851. No. 1, 97·0 feet in length, was completed on 15th March, 1851.

The loading of the mines was commenced on the 21st March, 1851, at one o'clock, P. M., the tamping was completed by eight o'clock, A. M., on the 22nd, and all four mines were exploded simultaneously during the course of the day.

The effect of the explosion was, to precipitate into the river the outer edge of the hill, (see shaded part, *Fig.* 3,) and to break up the whole of the rock included between the dotted lines in *Fig.* 3. After the mines were fired, working parties were employed in wheeling the *debris* into the river, and little powder was used except on the base of the hill, at the level of the road, which was not much affected by the large quantity of powder exploded immediately above it.

The following detail may be of use in future works of this nature.

To avoid any chance that might exist of injuring, by the explosion, that part of the rock on which the road was to be carried, it was considered advisable to lodge the powder some few feet *above* the proposed level of the road; one gallery was accordingly commenced about 4 feet above the foot-path, and carried in horizontally; the other was commenced at the level of the path and was carried in with a slight rise.

This care appears to have been unnecessary, as in removing the *debris*, the rock immediately below the charges was found comparatively strong and uninjured.

The *galleries* were tunnels into the solid rock; timber framing to support the roof was not found necessary.

The main galleries were 4½ feet high and 4 feet broad. The branches were smaller 4 feet by 3½ feet. The tunneling was effected entirely by blasting with a small jumper of 1½ inches diameter and from 3 to 4 feet in length, worked by two sepoys sitting. The easiest way of working is no doubt to make the first blast at the top of the gallery, and to remove all stone that may be loosened by it. The subsequent blasts should then be arranged as to blow through into this opening. In driving these galleries the Sappers were told off into four reliefs, and the work proceeded without check, day and night.

In December, during which month the works were in full progress, each gallery was advanced 32·5 feet, being at the rate of a little more than 1 foot per working day of 24 hours. The total number of feet of gallery driven was 130; 358 lbs. of powder were expended in 176 blasts, varying in depth from 1 to 3 feet. The *cost* of driving a gallery may be estimated therefore per foot, as follows, including the cost of tools:—

16 sappers in four reliefs of 4 men each, equivalent to about,

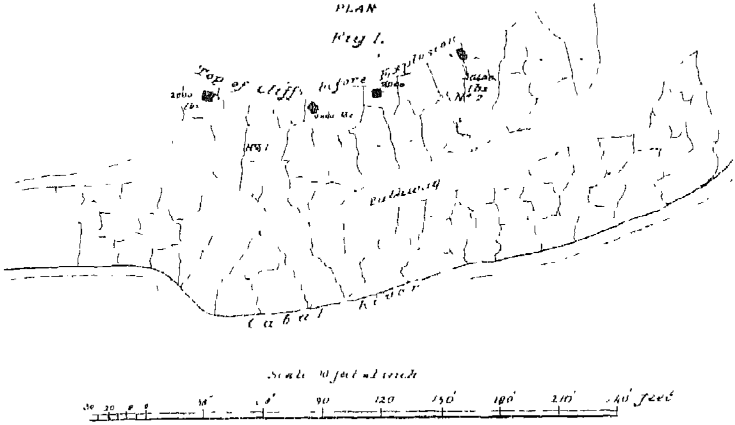
10 coolies, @ Rs. 0-2-6, ...	Rs.	1	9	0
2·6 lbs. powder, ...	„	0	3	11
Repairs of tools, &c., ...	„	0	3	1
Total per foot of gallery, ..	„	2	0	0

Speaking generally, it was found that a vertical shaft could be driven twice as fast

BLASTING ON THE LAHORE AND PESHAWUR ROAD.

PLAN

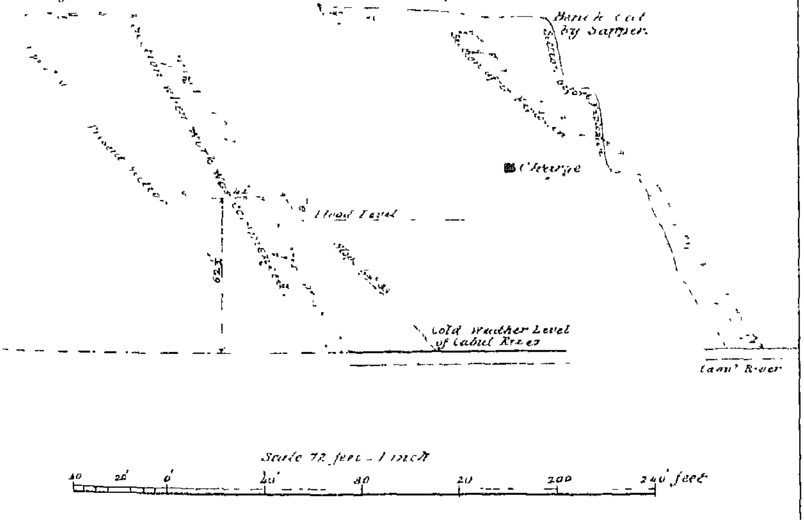
Fig 1.



Sections

Fig 2

Fig. 3



as a horizontal gallery, the area of the section of excavation being the same in each. Two of the *chambers* were worked exactly to contain the charges. The other two were formed so as to leave a space round the powder, but it is not possible to say which is the better construction.

Loading, Tamping, and Firing.—The powder was stored in the magazine in camp in bags, made of a cotton stuff, holding each 10 lbs. These were counted as they entered the mine. The hose was 1 inch in diameter filled with coarse native powder. It was prepared in the magazine in lengths of 50 feet, an arrangement which facilitated the measuring out of the hoses to the different chambers. It was protected in the galleries by a thin wooden casing, about one-third of an inch in thickness. The powder having been carefully lodged in the chamber, the end of the hose was introduced into the centre of the pile, conducted down to the floor of the chamber, thence placed in its wooden case, and laid along one side of the gallery; a thin wall of bags filled with clay and *debris* of rock was built at the end of the gallery to isolate the powder, and the floor of the gallery was then covered with 6 to 9 inches of *debris* to protect the hose. Till this was done, work went on in the dark, afterwards lanterns were freely used. A common candle in a lantern in No. 1 gallery, not more than 40 feet from the mouth would not burn. It was very warm in the gallery, but the men working in it experienced no other inconvenience. As the want of light delayed the work considerably, a common thermantidote was applied to the mouth of the gallery. It had the desired effect, and while it continued to be worked the lantern burnt freely.

In No 2 gallery, the candle burnt without the assistance of a thermantidote, which was probably owing to this gallery being somewhat more roomy than No. 1. The lodging of the powder was commenced at 1. P. M. on the 21st, and the tamping was completed at 7 A. M. on the 22nd, total 18 hours, being at the rate of 5½ feet per hour in each gallery. The working party was 36 sepoys, relieved three times in parties of 18, aided by 100 coolies, who worked from first to last.

The tamping having been completed, and the hoses all made of the same length, their ends were collected, attached to a piece of port fire, and covered to a depth of some inches with earth. The result was perfectly satisfactory. The hoses, about 135 feet each in length, burned so evenly, that all four mines exploded together, there being scarcely a perceptible interval between them.

Before firing the large mines, a number of smaller ones were exploded with Lines of Least Resistance of from 20 feet downward. The charges of some had been calculated at $\frac{(\text{L. L. R.})^3}{10}$ some at $\frac{(\text{L. L. R.})^3}{15}$; generally we found the charges calculated $\frac{(\text{L. L. R.})^3}{10}$ unnecessarily violent in their effect, while $\frac{(\text{L. L. R.})^3}{15}$ gave charges somewhat too weak. $\frac{(\text{L. L. R.})^3}{10}$ was adopted for the large mines whose Lines of Least Resistance were, respectively, commencing at No. 1, 30 feet, 40 feet, 30 feet 40 feet; and their charges 6,400 lbs., 2,800 lbs., 6,400 lbs., 2,800 lbs., total 98,400 lbs.

Powder.—The greatest part of the powder used was made by the officer in charge of the work, the materials having being procured in the neighbourhood of Attock, its average cost was Rs. 7-8 per maund of 80 lbs.

The Khoond Spur is of hard closely packed limestone. The total number of cubic feet of rock removed in the cutting is about 2,000,000 of which 1,840,000 cubic feet were effectually reduced to *debris* by the large mines, being at the rate of 100 cubic feet of rock per pound of powder.

201. *Side-hill Roads.*—When a road runs along the side of a hill, it will be most cheaply formed, by making it half in excavation and half in embankment. But as the embankment would be liable to slip, if simply deposited on the natural surface of the ground, the latter should be notched into steps, or off sets, in order to retain the earth. In adjusting the height of the made ground, an allowance should be made for its subsequent settling.

If the surface be very much inclined, both the cuttings and fillings will need to be supported by "retaining walls," which may be laid dry if composed of large stones, or in mortar. The proper thickness which should be given to them ought to be the subject of Mathematical investigation, but the mean thickness of the wall may be said to vary from one-fifth to one-half the height according to the varying values of the tenacity of the earth and the strength of the masonry. For further information the reader is referred to the Section on MASONRY.

If the side hill be of rock, the steep slope at which that material may with safety be cut, will enable the upper wall to be dispensed with.

When the road is required to pass along the face of a nearly perpendicular precipice, at a considerable height (a case which sometimes occurs in passing a projecting point of the rocky bank of a river in a mountainous district), it may rest on a frame-work formed of horizontal beams, deeply let into the face of the precipice, and supported at their outer end by oblique timbers, the lower ends of which rest in notches formed in the rock.

SECTION IX.—RAILWAYS.

CHAPTER XXXIX.

INTRODUCTORY—ALIGNMENT AND DIRECTION—CURVES—GRADIENTS.

202. The employment of a roadway with fixed Rails on which carriages or wagons were drawn by *animal* power dates from a very early period, having, as is well known, been largely employed on the collieries in England, but the first railroad on which Locomotives were fairly employed was the Killingworth colliery line, constructed by George Stephenson, in 1814. The Stockton and Darlington line which was next constructed, was at first only a colliery line, though it subsequently carried passengers, and the first line regularly constructed for the express purpose of carrying passengers and goods by steam power, was the Liverpool and Manchester Railway, opened in 1829. Since that time, with many improvements and alterations of detail, they have been constructed all over the world, and in 1851, the first small length of railway was opened in India. The great lines now under construction are most of them rapidly approaching completion, and will doubtless be the parents of many more branch and subsidiary lines.

203. The Railways hitherto constructed in India have been made under the *guarantee* system, the capital having been raised by the various Railway companies under a Government guarantee of a minimum dividend of 5 per cent. annually, on all sums duly passed to capital account by the Consulting Engineers. The result has been, that Government has exercised a complete control over the execution of the work, which has, perhaps, to some extent, retarded their execution, from the necessity of constant reference and correspondence, but which has at the same time been beneficial in many ways.

The first era of Indian Railways in which private enterprise has thus been dependent on a State guarantee, may now be considered to have come to a termination. Its fruits will consist, when all the lines in hand and projected are complete,—which may be expected to be the case about 1869,—of about 5,000 miles of politico-commercial first class trunk lines, which will have been constructed at an outlay of not less than seventy millions sterling. Of this sum, somewhat less than four millions, or about $5\frac{1}{2}$ per cent. of the whole cost, will have been actually contributed by the State (loss by exchange), whilst, under the very favorable supposition that the average profits on the lines all round will, in the same year (1869), come up to the amount of the guaranteed interest, the aggregate debt of the various Railway Companies to the State will probably amount to about nineteen millions sterling, of which fourteen millions will represent the net sums advanced by the State in payment of guaranteed interest during the construction of the lines, and five millions the simple interest that will have accrued on those advances. The assistance that has been rendered by the State in the construction of these lines may be estimated from these figures, and it must be admitted that the magnitude of its stake in the economical construction, maintenance, and working of Indian Guaranteed Railways was, and is, sufficient to justify the most careful and the most intelligent supervision and control, on its part, of the operations of the different Companies.

Whatever may be the ultimate position of the State in reference to these Guaranteed Companies, whether it recover its advances or not, there can be no question as to the immense advantages that the State will have derived directly in the administration of the country, *i. e.*, politically, and indirectly, in the prosperity induced by these lines of communications, *i. e.*, commercially. And, allowing that the State is fully reimbursed its advances, its absolute contribution will have averaged about £800* per mile of Railway, equivalent, at 5 per cent. as the market value of money, to an annual subsidy of £100 for $10\frac{1}{2}$ years, or of £64 for 20 years on each mile of Railway. But this is the least possible contribution of the State under the guarantee, and the failure of even one or two of the several lines to work at a profit sufficient to reimburse the State its advances, will augment this average contribution very materially; every million sterling that is not repaid adding £200 to it. The introduction of a system, free from the trammels and irresponsibilities of the guarantee, and more favorable to the State, under which the construction of standard and other gauge Railways in approved directions might be continued, has thus been a great and obvious desideratum.

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* $\frac{£4,000,000}{5,000} = £800$ per mile.

Such a system has now been introduced in connection with light branch Railways, and the following are the terms offered by Government, and which have been accepted in the case of two lines now under construction.

1st.—Eighteen feet surface width of a completed roadway to lay down its rails on.

2nd.—Land for extensions, diversions, sidings or stations, previous to date of completion of line, free of cost.

3rd.—The payment, on the completion of the line, of a sum equivalent to the Import duty paid on the permanent way material.

4th.—A subvention of Rs. 125 per mile open per annum as a contribution towards the cost of maintaining the road from date of opening the line for public traffic ; to cease, however, as soon as the net profits, exclusive of the subvention, shall for two years or for four half-years consecutively, amount to 5 per cent. on the capital.

On the other hand, the line is open to Government inspection; the tariff of charges is subject to restrictions; one train, at an average speed of not less than twelve miles an hour, including stoppages, must be run each way every day; special fares for troops, police and their prisoners, are provided; the mails are to be conveyed free of charge; and all persons or Companies shall be entitled to run properly constructed engines and carriages on the Railway, on the payment of proper fares and tolls, and under suitable regulations to be approved by the Government.

The concession of the roadway is for a term of 99 years, with right of purchase by the Government after 20 years from commencement of term; of withdrawal on the part of the Company within 5 years from that date ; and of entry with possession free of cost by Government, in case of default on the part of the Company at any time.

From these and the general conditions laid down for similar undertakings, the debatable points of the guarantee system have been eliminated; and the period has now arrived when experience of their suitability may be reaped. It is evident that the minimum of State interference, so long as the undertakings are, in any way, aided by the State, has been arrived at for it has been made so entirely the interest of the projectors to complete their works rapidly that the only interference necessary, on the part of the State, is such as may be requisite to ensure the safety of the public, and it is chiefly in respect of the constructive peculiarities introduced that the experiment has to be watched.

204. Railways may be conveniently treated of under the following heads:—Survey and Choice of the Line—Roadway—Permanent way—Rolling stock—Locomotives—Stations—Traffic.

As regards the first heading, it is evident that the general direction of the line from town to town is a question of traffic with which the Engineer will probably have little or nothing to do. His labors commence when it is a question of constructing the best and cheapest line between the towns which it is desired on commercial or other grounds to connect.

The cost of a Railway being so much greater than that of an ordinary road, and that cost in many items (such as Workshops, Terminal Stations, &c.), being not in any direct ratio to its actual length, it is often difficult to judge *a priori* as to whether the amount of traffic that will follow the construction of a given line, will be sufficient to pay a fair per centage on the heavy cost—or whether the returns per mile will increase in the same proportion as the constructing or working expenses. On the first introduction of Railways into India it was generally laid down as a principle, that the great lines should be carried from point to point by the shortest and easiest routes, and that it was the *through* traffic which was to be looked to to pay, rather than the local traffic. The results hitherto as far as they can be judged from, tend to reverse this conclusion and to show that it is the short local traffic which pays best, and that it is worth making a considerable detour to pick up such traffic, rather than leaving it to seek the line for itself.

Both in England and India the Passenger traffic was expected to form an inconsiderable item compared with that of Goods. Yet experience has amply proved what indeed might have been expected, that a ton of passengers while only requiring the same haulage power as ton of goods, can afford to pay a very much larger sum for the haulage, while the cheapness of water carriage almost prevents a railway carrying heavy goods at a sufficiently remmunerative tariff, to pay for the cost of haulage and wear and tear of the line.

The questions therefore to be gone into by the projectors of a line before the Engineer is called in, are the amount of Passenger and Goods traffic that may be fairly expected, and whether there is a competing line of water carriage which will force the Railway to adopt minimum tariffs. The Engineer will then be asked to estimate the cost; 1st, of Construction; 2ndly, Working expenses, including deterioration, when some idea may be formed as to whether the project will pay.

205. The general principles involved in the Survey and direction of the line, are the same as those already explained in the section on ROADS; but there are certain differences of detail which require to be noticed.

From the great cost of the superstructure of a railroad, and the continually increasing expense of keeping it in repair, it is highly desirable (part from the question of traffic) that it should be as straight, and consequently as short, as possible.

As the earthwork of a railroad costs almost nothing for repairs, while those of its perishable superstructure are very great, and proportioned to its length, as is also the cost (in fuel, wages, and wear and tear of the engines) of running the road, it will often be advantageous to make large expenditures for the former element of cost, in order to lessen the length of the road, and consequently the annual expenditure for the latter.

On these grounds, a *short* route, which has the faults of steep gradients and curves of small radius, may profitably receive an outlay of capital upon it, for the purpose of lessening these defects, equivalent to the cost of the difference of distance between it and a *longer* line, which has better grades and curves.

206. *Gradients.*—In the section on Roads it was explained how a steeper gradient could be allowed on a kucha than on a pucka road, the resistance of gravity to be overcome being the same in each case, and therefore bearing a much larger proportion to the frictional resistance in the latter case than in the former. For the same reason, the gradients on a Railway should be very much less steep than on a metalled road, the friction being so much less and therefore the loss of power due to the increased gradient being proportionally so much greater. On a good metalled road a horse can only draw, on a gradient of 1 in 24, *half* the weight which he can draw on a dead level, and as a rule the maximum ruling gradient should not exceed 1 in 30. A locomotive may be said to loss half its power at a gradient of 1 in 220; and the ruling gradient should if possible not exceed 1 in 275.

It is however, a more complicated question than that of a road. In both, of course, loss of power means loss of money, but in the case of a railway it also means wear and tear of permanent way and carriages in ascending, and increased danger in descending; on the other hand, it equally resolves itself into a case of comparative cost in the one case as in the other, and in forming a decision the *pros* and *cons* must be well weighed.

The cost of draught on a railroad is nearly as the power employed, so that it will cost nearly twice as much to carry a load on a railroad with an ascending grade of 24 feet to the mile, as to carry it on a level route. This consideration will therefore justify large expenditures upon the excavations, embankments, &c., of a railroad, with a view of reducing its grades. The propriety of such expenditures is to be determined by comparing the annual interest of the amount with the annual saving of power ever after, in drawing the expected loads over the flattened road. It will therefore be useful to investigate the resistance to be overcome on a level road, so as to determine the absolute increase produced by a gradient.

207. The resistance to be overcome has three principal elements; Friction, Atmosphere, and Concussion.

The first resistance is that of the *Friction* proper of the wheels and axles. It is constant at all velocities, and amounts in the best constructed carriages, to 6 lbs. per ton weight of train.

The second resistance is that of the *Air*. It is considered to be proportional to the surface of the front of the train, and to the square of the velocity. It equals the weight of a column of air, whose base is the frontage of the train, and whose length is the height due to the velocity. This weight for each square foot of frontage, and for a velocity of one mile per hour, equals 0 0027 lbs., or $\frac{1}{400}$ lb. For the usual frontage of 80 square feet, it is therefore one-fifth of a pound at one mile per hour.

The third, or *residual* resistance, is probably due to the unavoidable *concussions*, oscillations, flexures, imbedding of wheels in rail, friction of air against sides, &c. It may be hereafter decomposed into various elements, but is now taken as proportional to the weight of the train and the velocity, and as being equal to $\frac{1}{3}$ lb. for each ton of train, at one mile per hour; whence the following formula is derived:—

Let T, denote the weight of the train, *in tons.*
V, its velocity, in miles an hour.
A, its area of frontage, in square feet.
B, its volume, in cubic feet; then

$$\text{resistance in lbs.} = \left[6 + \frac{V}{3}\right] T + \frac{V^2 A}{400}\text{; or}$$

$$= \left[6 + \frac{V}{15}\right] T + \frac{V^2 B}{50000}.$$

The above formula has been tested by Mr. Scott Russell and Mr. Wyndham Harding, chiefly for passenger trains of from 20 to 64 tons, and at speeds from 30 to 60 miles per hour. At lower velocities, its results somewhat exceed those of the experiments.

The following table shows the Resistances to trains of different weights, and at different velocities, as given both by actual experiments and by the above formula: the frontage being 60 square feet.

Velocity	Weight.	Resistance by Exper.	Resist by Formula	Velocity.	Weight	Resistance by Exper.	Resist by Formula
mls per hr	tons	lbs per ton	lbs per ton	mls per hr	tons	lbs per ton	lbs per ton
14	9	12·6	13·9	34	30½	25·0	23·1
16	20½	8·5	13·2	34	18	23·4	27·2
19	40⅔	8·5	12·9	35	21½	22·5	26·1
21	18	12·6	16·7	39	24	30·0	31·0
25	40¼	12·6	16·6	47	31¾	33·7	33·1
27	40¼	12·6	17·7	50	30	32·9	35·3
31	15½	23·4	25·4	53	25	41·7	42·1
32	14½	22·5	27·2	61	21½	52·6	54·8

The above being the resistance to be overcome on a *level*, the resistance on a gradient is equal to that on the level + that of gravity due to the ascent, which is such a part of the whole load, as the height of the ascent is of its length.

Let then, f = resistance (in lbs. per ton) on a level.

h = ascent in feet per mile; and $\frac{h}{5280}$ = inclination.

$$\frac{h}{5280} \times 2240 = \frac{14h}{33} = \text{resistance per ton of gravity.}$$

$$f + \frac{14h}{33} = \text{total resistance on the inclination.}$$

The power required to overcome this resistance will be discussed further on.

208. In the early days of railway making greater importance was attached to the question of gradients than is now the case ; and in France, even as late as in 1846, Mr. Locke had great difficulty in persuading the authorities to tolerate inclines of a rise of 1 in 126; but upon the Birmingham and Gloucester line, the Lickey incline, with a gradient of 1 in 37, has been for years in successful work; and in the passage of the Sœmering, on the Vienna and Trieste railway, the inclines are sometimes carried for great distances, at the rate of 1 in 40, and the radii admitted in the curves upon the level parts are often not more than 623 feet, whilst upon the inclines of 1 in 40 they are still occasionally of only 934 feet; the length of the arcs in the latter cases does not exceed 1,300 feet in round numbers. Of course the speed over lines with inclines of so severe a nature cannot be great, but the introduction of the expansion gear into the locomotive has so much increased what may be called the elasticity of its powers, that at the present day an incline of 1 in 100 would not be regarded as unfavorable, and the former limit of 1 in 200 would not be a matter of a moment's hesitation.

The gradients on Indian lines are generally very light, the greater part of the country being very flat. On the Punjab railway the maximum ruling gradient was defined to be 1 in 1,000, the only exception being at the approaches of two of the bridges. As a contrast there is a gradient of 1 in 37 on the Bhore Ghât Incline (Great Indian Peninsular Railway).

209. *Curves.*—The importance of *curves* in the case of a Railway is much greater than in that of a road, as will be explained further on in the chapter on Permanent Way. In laying them out, one or other of the methods may be adopted which have already been explained in the Section on Roads. Curves of 800 feet radius are often resorted to when on account of the approach to a station, the speed of a train must be slackened; but it is hardly safe to admit them of a less radius than about ¼ mile on the ordinary parts of the line.

As curvature of the line increase the resistance of trains and the danger of jumping off the line at high speeds, it is advisable to avoid very sharp curves on steep gradients, and on parts of the line where the speed is to be very high.

Where sharp curves necessarily occur in the course of a steep ascent it is advisable, instead of adopting an uniform gradient, to make it slightly steeper on the straight parts of the line, and slightly flatter on the curved parts, in order that the resistance of an ascending train may be as nearly as possible uniform.

Both engines and carriages are adapted on American lines to sharp curves by means of the "bogey," a small four-wheel-truck, with its wheels as close together as possible, capable of turning about a pivot into various positions relatively to the carriage or engine which it supports, and having a platform on which the carriage is supported by rollers. A long passenger carriage is supported on two bogeys, one near each end; a locomotive engine has one bogey under the leading end, the after end being supported on one or two pairs of driving wheels. By the aid of these contrivances engines and carriages are enabled to pass round curves of radii as small as 3½ chains (231 feet).

On the Bhore Ghât Incline, mentioned above, the sharpest curve has a radius of 15 chains on an incline of 1 in 75.

CHAPTER XL.

FORMATION OF ROADWAY—TUNNELS—CROSSINGS—FENCING.

210. The *Excavations* on railways are often of much greater depths than are ever necessary on common roads, the extra expense being amply repaid by the advantages of the easier grades and straighter lines thereby attained. The thorough drainage of these excavations by ditches, cross-drains, &c., is of the highest importance. Their sides often need to be supported by retaining walls, in order to make steeper slopes possible, and thus to lessen their top width, when they pass through valuable ground. Sometimes these retaining walls are supported by iron beams, or flat arches, extending across the railway at a sufficient height to clear the engines.

The *Embankments* of railways demand the use of every possible precaution to ensure their solidity; not only on account of their size, but because the vibrations imparted to them by the passing trains, greatly increase their tendency to slip. The expense and time required to form them in layers, often forbid the adoption of that method. They are usually constructed by raising them to their full height at one end, and so carrying them onward. Temporary rails are laid along the bank and extended with it, and on them wagons, containing each about 3 cubic yards, are drawn by horses, or by locomotive engines, if the distance, or "lead," be great.

The tops of the embankments, and the bottoms of the excavations, are brought to a height called the "Formation level," about 2 feet below the intended level of the rails, and there shaped with a fall from the middle to each side, as in common roads, in order to drain off the water which falls upon them.

The rules for the laying out, calculation and actual construction of Cuttings and Embankments will be found in the Sections on Earthwork and Roads, and need not be repeated here.

211. Instead of metalling, *Ballast* is employed on the top of the formation surface, in which the sleepers are imbedded which carry the chairs and rails. The use of this ballast is to protect the formation surface—to keep it dry—and to act as a firm, but not rigid, bed for the permanent way. In England gravel is usually employed, sometimes chalk. In India, kunkur where procurable, or broken stone or *roree* (broken brick). Sand has also been employed with success where other material was not available.

The ballast is put on to a total depth of about 18 inches or 2 feet; 12 inches are usually first laid down, the sleepers are then laid on at proper intervals and the ballast properly and carefully hand-packed all round and under them.

212. The following was the specification for the ballast laid down on the Jubbulpore Railway:—

The ballast will consist of hard broken stone, clean gravel, clean kunkur or hard well-burnt clay; or of well-burnt broken bricks, or other approved material of equally good quality.

The ballast is to be broken to such a size as will pass in all directions through a ring 2½ inches in diameter.

The portion of ballast immediately on the formation, at the discretion of the Engineer, may consist of coarsely broken stone or other specified material.

There will be about 158,400 cubic feet of ballast required per mile for a single line, with an additional allowance for sidings and metalling.

213. The roadway is often made for a single line only at first, but ground is taken sufficient in width for a double line hereafter if required; spare ground should also be taken on one or both sides for depositing materials for the repairs of the line as in the case of a road. The width to be so taken must depend on the price of the land, as if too dear it can be dispensed with.

The width required for stations, workshops, or other buildings, should be carefully calculated beforehand and applied for at the same time as the land required for the roadway. It is better to apply for too much than too little, as the making of the railway is sure to raise the price of the adjoining land, so that if applied for afterwards the cost might be excessive, while if too much had been taken up, it might be sold at a profit.

214. The *Breadth of Formation or Base* depends upon the gauge, or clear distance between the rails of a track, the number of tracks, the clear space between them, the clear space left outside of them for projection of carriages and for men on foot, and the additional space required for the slopes of the ballast, the side drains, &c. The following are examples:—

SINGLE LINE

		Narrow Gauge Ft	Narrow Gauge In	Indian Gauge Ft	Indian Gauge In
Clear space outside of rail,		4	0	4	0
Head of rail,		0	2½	0	2½
Gauge,		4	8½	5	6
Head of rail,		0	2½	0	2½
Clear space outside of rail,		4	0	4	0
Least breadth of top of ballast, and least width admissible for archways, &c., traversed by the railway,		13	1½	13	11
Spaces for slopes of ballast, and benches beyond them on embankments,	from	3	10½	5	1
	to	8	10½		
Total breadth of top of embankments,	from	17	0	19	0
	to	22	0		

DOUBLE LINE

		Narrow Gauge Ft	Narrow Gauge In	Indian Gauge Ft	Indian Gauge In
Clear space outside of rail,		4	0	4	0
Head of rail,		0	2½	0	2½
Gauge,		4	8½	5	6
Head of rail,		0	2½	0	2½
Middle space (called the "*six feet*"),		6	0	6	0
Head of rail,		0	2½	0	2½
Gauge,		4	8½	5	6
Head of rail,		0	2½	0	2½
Clear space outside of rail,		4	0	4	0
Least breadth of top of ballast, and least width admissible for archways, &c., traversed by the railway,		24	3	25	10
Spaces for slopes of ballast and benches beyond them, on embankments,	from	3	9	5	2
	to	8	9		
Total breadth of top of embankments,	from	28	0	31	0
	to	33	0		

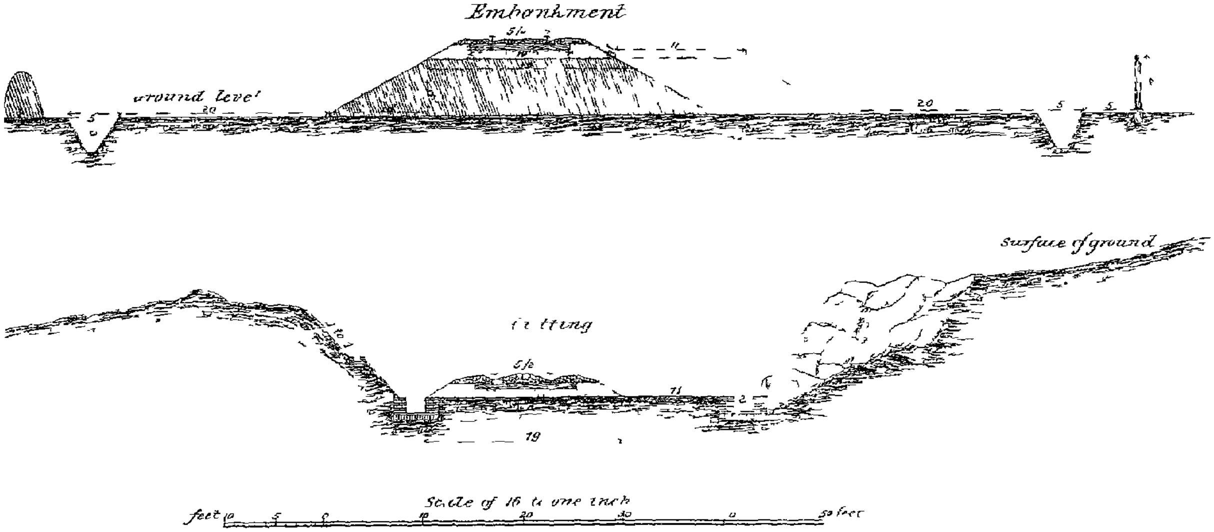
Cuttings are sometimes made of a width at the formation level equal to that of the embankments on the same line; in other cases they have an additional width given to them, to allow space for the side drains

215. *Tunnels*—In consequence of the easy gradients required for Railways as compared with roads, the depth of cutting is often very great and when that depth increases beyond a certain maximum (usually about 60 feet) it is more economical to resort to a tunnel.

The nature of the strata through which a proposed tunnel is to pass should be carefully ascertained, not only by means of borings and *shafts*, but in some cases also by means of horizontal mines or *drifts*, along the intended course of the tunnel.

The most favorable material for tunneling is rock that is sound and

CROSS SECTION OF AN INDIAN RAILWAY



durable without being very hard. Great hardness of the material increases the time and cost of tunneling, but gives rise to no special difficulty. A worse class of materials consists of those which decay and soften by the action of air and moisture, as some clays do; and the worst are those which are constantly soft and saturated with water, such as quicksand and mud.

In choosing the site of a tunnel, regard should be had, not only to the nature of the material and to the shortness and directness of the tunnel, but to the facility for getting access to its course at intermediate points by means of shafts and drifts.

The Engineer should, as far as possible, avoid curved tunnels, especially those in which the curvature is so sharp or so extensive as to prevent daylight from being seen through from end to end.

Tunnels made in rock that is so sound as not to require a lining of masonry or brick-work to prevent pieces of it from falling in, may be made, if the rock is igneous, of almost any shape that is most convenient for the traffic. The elliptical or horse-shoe form is, however, generally adopted for the sides and top, the floor being level. In stratified rocks, the strongest form for the roof is that of a pointed arch; though a flat roof has been used where the rock consists of thick layers, and has few natural joints.

In ordinary tunnels, measured within the masonry or brick work, the dimensions of most common occurrence are—

	Height.	Width
For single lines of railway,	20 ft.	15 ft.
For double line of railway,	24 ft.	from 24 ft. to 30 ft.

Shafts or pits are sunk for three purposes; to ascertain the nature of strata to be excavated, when they are called *trial shafts;* to give access to a tunnel when in progress for the purposes of carrying on the work, removing the materal excavated, admitting fresh and discharging foul air, and pumping out water, when they are called *working shafts;* to admit light and fresh air at intervals to, and remove foul air from, a tunnel when completed, when they are called *permanent shafts.*

216. *Trial Shafts* are in general sunk at or near the centre line of the proposed tunnel. Their transverse dimensions are fixed mainly with a view to convenience in sinking them. Six feet is an ordinary diameter for a round trail shaft; 6 feet by 4 are ordinary dimensions for rectangular shafts. The shape is regulated by the material to be used in lining the shaft, being rectangular in timbered shafts, and cylindrical in those that are *steined* or lined with stone or brick

The number and distance apart of trial shafts are to be determined after previous boring, no general rule can be laid down on the subject; but the Engineer must, to the best of his judgment, sink such shafts as are necessary in order to give him an accurate knowledge of the strata to be excavated.

Working Shafts may be either rectangular or round Their usual transverse dimensions range from 6 to 9 feet; the greater diameter is advantageous, because of its admitting of large quantities of material being raised and lowered at a time. Their distance apart varies, in ordinary cases, from 50 to 300 yards. In some cases, however, it has been found necessary to place them as close as 20 or 30 yards apart, for the purpose of discharging foul air; while in other cases the height of the ridge to be tunneled through has rendered the sinking of shafts impracticable for very long distances. An extreme example of the last case is the tunnel now in progress through Mont Cenis, which, when complete, will be eight miles long, and which must be excavated entirely from the two ends, without the aid of shafts.

The range of working shafts of a tunnel may lie either along its centre line, or in a line parallel to the centre line, at an uniform distance to one side. When the latter system is adopted, the object is to keep the shafts clear of the excavation and building of the tunnel, with which they are connected by cross drifts, or headings.

Permanent Shafts are in general working shafts that have been made permanent parts of the structure; the brick lining of each being supported on a permanent *curb* or suitably formed ring of brickwork, or of cast-iron, surrounding a circular orifice in the roof of the tunnel. The top of each shaft is protected by being surrounded with a wall, and covered with a grating.

Tunnels in dry and solid rock are generally excavated by driving a heading immediately below the intended roof of the tunnel, from which heading the excavation is extended sideways and downwards by blasting and quarrying.

Drifts or Headings are small mines or galleries driven along the line of the tunnel to explore the strata, drain off water, or remove the stuff excavated. The least dimensions of a heading in which miners can work are

3 feet wide, and $4\frac{1}{2}$ feet high. If the soil is loose the sides and roof of the mine must be supported by a timber frame-work.

217. The following data, on the authority of Becker, show the distribution per cent of the cost of excavating a railway tunnel in Jura limestone, which required 1·15 days' work of a miner to excavate each cubic yard:—

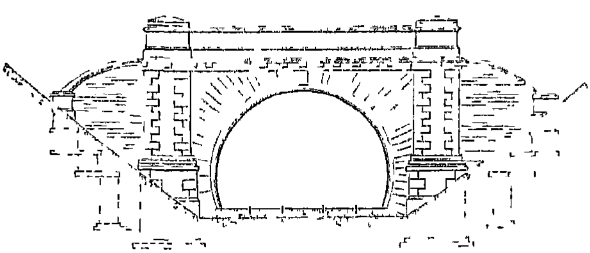
Workman's wages, ...	45	per cent
Blasting powder, ...	15	,,
Fuses, ...	3	,,
Lamp oil, ...	8	,,
Boring tools, ...	29	,,
	100	,,

This tunnel advanced at the rate of about a foot per day.

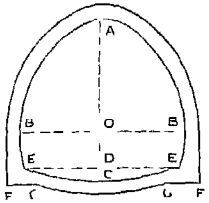
Tunnels in soft materials, whether such as are soft from the first, or such as become soft by exposure to air and moisture, like some kinds of clay, require timbering to support the sides and top of the excavation, and to be lined with brickwork to prevent their falling in.

The bottom of the excavation is formed with great accuracy to receive the invert, or inverted arch, which forms the base of the brickwork. The invert and side walls are built according to moulds, and the arch of the roof upon centres, consisting of three ribs under each length. The best centres have ribs of iron, with screws under each laggin. The centres are usually supported on cross sills, which are themselves supported partly by posts resting on the floor, and partly by their ends being inserted into holes in the side walls which are built up after the centres are struck.

After the brick-work of length has been built, most of the crown bars which lie above the arch can be pulled forward so as to serve for the next length; those which resist this must be left. All spaces between the brickwork and the earth must be carefully rammed up.



The labor of executing brickwork in tunnels (including cost of lights) is about double that of executing the same quality of brickwork above ground.



The figure shows a section of an elliptical tunnel with an inverted arch ECE at the floor. The parts FG, GF, of the base, which directly bear the side wall and their load, are horizontal. O is the centre of the ellipse EBABE, BB the minor axis, AOC about three-fourths of the major axis.

The following was the distribution of the cost of Blechingley tunnel, according to Mr. Simms:—

	Per cent.	
MATERIALS.		
Bricks, ...	30½	
Cement, ...	11	
Timber, ...	11⅓	
Iron Works, ...	2½	
Miscellaneous, ...	6⅓	
	——	62
LABOR.		
Mining—Shafts, heading, &c., ...	3¼	
„ Tunneling, ...	15¾	
	——	19
Brickwork, ...		12
MISCELLANEOUS EXPENSES.		
Such as tunnel entrances, culvert machinery, buildings, inspections, &c., ...		7
		100

The total cost per yard forward was about £72; the clear dimensions of the tunnel being 24 feet × 24 feet, and the brickwork from 1 foot 10½ inches to 3 feet thick.

218. The Monghyr tunnel, the only tunnel on the East Indian Railway between Calcutta and Delhi (1,025 miles) is 900 feet in length, on a rising gradient of 1 in 500 up to within 75 feet of the west face where the gradient *falls* 1 in 500. The dimensions within the brickwork are, from rails to soffit 23 feet, and width 26 feet. The tunnel passes through an outlying ridge of the Vindhya range of hills exhibiting the junction of the quartz and clay slate. On the east side of the hill, the tunnel has to be cut through clay slate upheaved and contorted, and on the west side through quartz rock. The whole of the tunnel is lined with brickwork, in consequence of the nature of the rock and the quantity of water percolating through fissures, &c., in the roof. The work was carried on at both ends by a top heading.

On the Bhore Ghât Incline, 13 miles long, there are no less than 26 tunnels of a total length of 3,987 yards, of which 412 yards are artificially lined with stone.

219. *Ranging and Setting-out Tunnels.*—The centre line of a tunnel having been at first ranged on the surface of the ground, a row of shafts are sunk in convenient positions along that line.

In order to range the line below ground, it is necessary to have two marks in the centre line at the bottom of each shaft, as far asunder as possible, to enable that line to be prolonged from the bottom of the shaft in both directions. Those marks consist of nails or spikes driven into the cross timbers.

The former practice was to determine the positions of those marks below ground, by erecting over the shaft a timber frame, from which two plumb lines were suspended, hanging nearly to the bottom of the shaft, and to range those plumb-lines by the transit instrument; but as that process is difficult or impossible in windy weather, Mr. Simms introduced the following improved methods:—The Engineer ranges, by the transit instrument, two strong stakes in the centre line, above ground, each about 16 feet from the centre of the shaft, so as to be safe from disturbance while the work is in progress. To mark the exact position of the centre line, each stake has driven into its head a spike with an eye through its top. The eye of each spike is very carefully ranged in the exact centre line, being made visible to the observer at the instrument by holding a piece of white paper behind it. A cord is stretched through the holes in the spikes, so as to mark the course of the centre line across the mouth of the shaft. At each side of the shaft a plank is laid at right angles to the string, and with its edge over-hanging the edge of the shaft 2 or 3 inches, so that a plumb-line may hang from it clear of the side of the shaft. Two plumb-lines are then hung from the planks, directly under the cord that marks the centre lines; and the lower ends of those plumb-lines show two points in the centre line at the bottom of the shaft.

The approximate ranging of the "heading" or "drift;" or small horizontal mine that connects that lower ends of the shafts, is performed by means of candles, each hung from the timber framing in a sort of stirrup.

The accurate ranging of the centre line, after the heading has been made, is performed by stretching a cord between the marks already ranged at the bottom of the shaft and fixing at intervals of 30 or 40 feet, either small perforated blocks of wood carried by cross-bars, or stakes with eyed spikes driven into their heads, so that the holes in the blocks or spikes shall be ranged by the cord exactly in the centre line. The centre line of any part of the tunnel can then be marked at any time when required, by stretching a cord through two of those holes. The cross-bars are fixed in a temporary way to the timber framework of the heading so that they can be removed, to leave free passage for men and wagons; but their places are so marked that they can be refixed exactly in their proper positions at any time when it is required to range part of the line.

Curves can be set-out below ground by means of a theodolite on a short-legged stand, and candles or lamps instead of ranging-poles. In this case, the two marks at the bottom of a shaft indicate the direction of a tangent to the curve at its centre.

When the line of shafts does not follow the centre line of the tunnel, but a line parallel to it, a corresponding line is to be set-out through the heading at the bottom of the shafts; and from that line the centre line, or any given part of the tunnel, can be set-out by laying down off-sets in the transverse headings.

220. In order to *set-out the levels of a tunnel*, there should be a bench-mark above ground, near the mouth of each shaft. When the shaft has been sunk, and lined with timber or brickwork, a second benchmark is to be made within the shafts and near its top, by driving into the timber or brickwork a horse-shoe shaped staple in a horizontal position, the levelling staff being held on its upper surface in taking its level.

Some part of the masonry or brickwork of the intended tunnel is taken as a standard point by means of which the levels of other points are regulated; for example, the " invert skew-back," or joint where the inverted arch forming the bottom of the tunnel meets the sides. That joint being at a fixed height above or below the rails, (generally below,) its depth below the staple is to be calculated. That depth is then to be set-off by hanging through the staple a chain of rods of the proper length. The rods used by Mr. Simms are connected together at the ends by eyes and spring-hooks; the length of each rod, from the inside of the eye at one end to the inside of the hook at the other, is 10 feet. To set off a given depth below the staple, the number of rods to be linked together is one more than the number of entire tens of feet in the depth; the odd feet and decimals of feet are set off on the uppermost rod by screwing a gland upon it at the proper point. The chain of rods is then dropped through the staple until the gland, resting on the staple, prevents them from passing further, and supports the whole chain; a bench-mark, consisting of a flat-sided spike driven horizontally into the timbering, or of a stake with a round-topped spike in its head, driven vertically into the ground, is then adjusted at the bottom of the shaft, so that its upper surface is exactly on a level with the bottom of the lowest rod.

The staple forms a permanent bench-mark, through which the rods can be lowered again, whenever it is necessary to make a new bench-mark under ground, owing to disturbance of the former bench-mark. This is always done after the brick-work has been partly built, in order to make a permanent bench-mark, by driving a flat spike into the side of the tunnel.

221. *Crossings and diversions* of other lines of conveyance. When the course of a railway crosses that of a previously existing line of land-carriage, the railway may either be carried over or under the existing line by means of a bridge, or across it on the same level. When a canal or a river, is to be crossed, the railway must be carried either over or under it. In order to facilitate such crossings, it may be necessary to alter the level or divert the course of existing lines of conveyance; and in some cases a diversion may be required independently of any crossing. The parts of a road whose levels are altered for the purpose of carrying the railway across it, are called the *approaches* of the crossing.

Previously existing roads may be crossed on a level when the crossing is said to be a *Level Crossing;* or at a lower level when the bridge carrying the road over the rail is called an *Over-bridge*, or at a higher level when the bridge is called an *Under-bridge.*

Level Crossings are always to be avoided if possible, especially in a populous district as dangerous. In England they are all but prohibited for public roads. In a level country, however, they can hardly be avoided without great expense and they are numerous on Indian Railways. They should have double gates shutting across the road on both sides of the rail, and across the railway when open, so as to prevent animals straying on the line. Self-closing gates are occasionally used, but as a rule a gate-keeper should be provided.

Over-bridges should have a clear head room of 15 feet over both lines of rail and the width of the rail track should not be diminished to less than 25 feet; beyond this they will follow the ordinary rules for road bridges. In dangerous soil, however, special precautions should be taken to prevent the vibration of the trains passing below disturbing the foundations; in such cases an invert should connect the two abutments so that the whole bridge may shake together.

Under-bridges should have a clear head room of 12 feet, to enable a loaded elephant or wagon to pass, and the width should not be less than 16 feet for a public road. As they have to carry the railway and to stand the vibration of trains going over them, they should be made of the very best masonry and the depth of the arch should be somewhat greater than for a road bridge. Iron Girders are now generally employed.

When roads are diverted to cross the line the approaches should not if possible have a steeper inclination than 1 in 30.

222. *Fencing.*—On the land being made over to the Railway authoritise it should be at once marked off and fenced in.

Almost all Railways are fenced on both sides. In a populous country it is essential to prevent trespassers on the line and to ensure trains from accidents by stray cattle. In America however, the lines generally run unfenced through thinly populated districts, and on the Lahore and Mooltan line the same system was proposed, but I believe was overruled.

The most common descriptions of fence are the ditch and bank—walls of mud or dry stone—the post and rail—wire fencing of several sorts, and various kinds of hedges. In the first kind, the earth dug from the ditch is thrown up into a bank, and both should be made deep or high enough to prevent cattle getting over. This kind of fence is easy and cheap to make, but requires constant repair and is generally only a temporary substitute for a more permanent sort. If intended to remain, some plant like the cactus should be planted on the top of the bank.

Mud walls may be used in the drier parts of India, but they also require constant repair; the same may be said for *dry stone walls*, where the materials is procurable.

The *post and rail* is more effective as an obstacle; unless, however, the wood is kyanised or otherwise expensively defended from the attacks of insects it is quickly destroyed and is always wanting repair.

Wire fences are common in England and have been introduced into India. The posts may be of wood connected with 4 or 5 wires, about the same thickness as telegraph wire, or the standards themselves may be of iron. At intervals a straining post is used by which the wires can be tightened or slackened. This fence is effectual enough if carefully put up, but is very expensive and apt to be stolen. A writer in the Calcutta Engineer's Journal recommends a wire fencing on standards consisting of *live* trees planted at proper intervals apart, and the idea seems a very good one for this country.

The best fence is undoubtedly a quick-set hedge or other evergreen; but in India it is often difficult to grow in consequence of the scarcity of water and the difficulty of supervision; even under favorable circumstances from 3 to 5 years are needed before it is strong enough to be a perfect obstacle, until which time a temporary fence must be used.

"The best kind of wooden fencing cut out of timber logs and properly tarred over, costs Rs. 30 per 100 lineal feet or Rs. 3,180 per mile. A strong and serviceable iron fence on the other hand composed of wire strand with bar iron standards costs in England £206 per mile. Add to this £30 per mile for freight and insurance to Calcutta or Bombay, and say Rs. 400 per mile for inland transit and erection, there would still be a saving of Rs. 420 per mile, in favor of the iron fence."*

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* Calcutta Engineer's Journal.

CHAPTER XLI

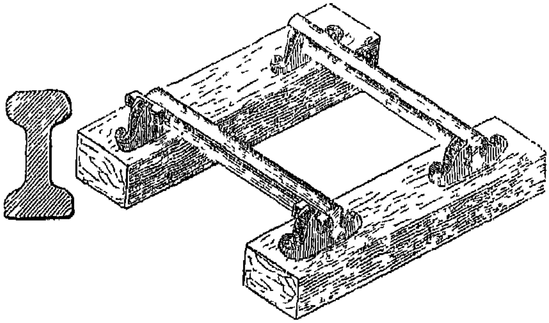
PERMANENT WAY.

223. Much discussion has, from the first introduction of Railways, taken place as to the best form of Permanent Way, and the practice is even now anything but uniform. The first rails were simply bars of flat iron supported on wooden blocks, fixed at intervals on the formation level. Stone blocks were then substituted for wood, but have now generally been abandoned, as too rigid and inelastic.

The general qualifications required in any system of permanent way are —1st, That it should be fixed so firmly that the gauge, *i. e*, the distance between the rails shall always be preserved, otherwise the carriages would be thrown off the line; 2nd, That it should preserve a horizontal position across the line (except in the case of curves), otherwise there would be danger from the centrifugal force, especially at high speeds, and the unequal pressure would injure both engines and carriages; 3rd, That it should preserve an even position lengthways, otherwise the carriages would proceed in a succession of bumps or jerks, which would cause a loss of power from increase of friction, and be highly dangerous to springs and axles; 4th, That there should be a certain elasticity in the roadway, whereby the rigidity of impact between rails and wheels will be avoided, such rigidity being dangerous to the axles, and causing much wear and tear; 5th, That the friction between the wheels and rails should be a minimum beyond the amount necessary to ensure the wheels *biting;* 5th, That the rails should be strong enough between the points of support to bear without changing form, the greatest weight liable to come upon them.

At first the plan was tried of fixing the flange on to the rail, but experience quickly showed that this was inferior to fixing it on the wheel, and the wheel tire and flange were made in their present form, to allow a certain amount of free play. As the carriages employed were heavier and the pace faster, the rails were found too weak and accordingly strengthened, but as strength was evidently required in proportion to the distance of the rail from its point of support, the *fish-bellied rail* was introduced as a more economical means of employing the necessary quantity of material. At this time, however, cast-iron rails were alone employed as cheaper, but it was soon seen that for heavy carriages and increased speed they were too brittle to be trusted, and wrought-iron quickly usurped its place. Thence the fish-bellied pattern was abandoned as being more difficult to roll, and the saving of material not compensating for the extra cost. The double T headed rail was then invented, and has since held its ground pretty firmly against all later inventions. We shall therefore describe it here, and then give some account of the more important of other descriptions in use

224. The section is shown in the figure. The rail is supported on



cast-iron chairs, which are spiked down to wooden sleepers laid across the breadth of the line; the rails being brought into exact position, and made to preserve their true gauge by wooden keys. Of each of these separate parts we may now speak in detail.

Sleepers are generally made of wood, though sometimes of iron; they are usually rectangular in section, about 9 or 10 by 6 or 7 inches, and long enough for both rails to rest on with something over on each side, say 9 feet for Indian Railways, where the gauge is 5½ feet. Triangular sections have been used with the base upwards; or a semi-circular section with the flat side up, two sleepers being sawn out of each round log. Both these are commonly employed for temporary lines, or in places where timber is dear, and where a cheap line is desired with low speeds.

The sleepers are placed from 2½ to 4 feet apart, the distance being lessened as the gauge and weight of engines increase, or the strength of the rail diminishes. They should be laid carefully in the ballast, which should be hand packed under and around them, and which generally just covers the upper surface of the sleeper.

Various kinds of wood are used for sleepers in different countries; the timber should be heavy, tough, and impervious to heat and damp, or the attacks of insects, and the wood which has the most of these qualities is of course the best, but economy has to be duly considered in making the choice, and this often obliges us to use inferior woods for the purpose. English sleepers are usually of Scotch or Riga fir, or Swedish or Memel pine. In India, teak, saul, and deodar are the woods which have chiefly been employed. The wood should be thoroughly seasoned, and if possible kyanized. It is a fact, however, that when once trains are running, sleepers are rarely attacked by white ants, the vibration of the trains probably destroying them before they can make a permanent lodgment.

On the Sind Railway, among the kinds of wood used for sleepers, the deodar was found to be the cheapest; and when steeped in sulphate of copper or Burnettizing solution, very durable. English creosoted pine stood well, except that, owing to the extreme dryness of the climate, it was liable to twist and split, and in the latter case became exposed to the attacks of white ants. The cost of the deodar, delivered at Kotree was Rs. 3 per sleeper; that of creosoted pine, Rs. 4-7 (8*s.* 11*d.*) delivered in Kurrachee. The cost of Burnettizing at Kotree was 3 annas per sleeper, and this was found superior to the sulphate of copper process, inasmuch as wood prepared with the latter rapidly corroded nails or spikes driven into it.

Chairs.—On the wooden sleepers are fixed the *Chairs*, by means of two wrought-iron spikes, driven vertically through the sleeper, each of which carries two chairs one for each rail. The chairs are made of cast-iron, and weigh about 20 lbs. each. The upper part of the chair receives the rail, which, as above said, is fixed tightly to it by means of the wooden *Keys* or wedges. These should be of oak, or other hard-wood; those employed in India are English made, and the wood is compressed by powerful machinery. By striking these keys with mallets, the line is kept in accurate gauge, and it is the duty of the inspectors, after the line is opened for traffic, to have the length under their charge constantly measured to see that the gauge is accurately preserved.

225. *Rails.*—These are made usually in lengths of about 20 feet, and are fitted on to the chains in the manner above described Where two rails unite, what is called a *fish-plate* is used to connect them, which is simply a piece of bar iron, about 2 feet long, laid sideways and fixed to both rails by four screws and nuts.

The double-headed rail is in effect a small girder, but one intention in giving it originally its present form was, that when the upper head was worn out by the traffic, the rail should be turned upside down, though I am not aware that this has ever actually been done on any line.

Rails are or should be made of the best and toughest iron, rolled very carefully in the rolling mill; they are subject to *abrasion* of the upper surface from the wear and tear of traffic, and from *lamination*, *i. e.*, a tendancy to split off in layers from the continual pressure of the wheels. Their weight per lineal yard, *i. e.*, the actual area of their cross section, depends on the nature and amount of traffic which they are to carry. Those on the East Indian Railway, weight about 84 lbs., which is rather above the average weight in England. On the Punjab Railway the weight is only 66 lbs., the amount of traffic not being likely to be heavy. Theoretically, as before stated, the section should be strong enough to prevent any possible change of form from the heaviest trains running over it, with an ample margin of safety and allowance for abrasion. The speed as well as the weight of the trains is also to be taken into account in practice, and though its effect upon the rail cannot be theoretically calculated, it seems generally admitted that it should be cared for. Supposing the points of support for the rails (*i. e*, the chairs and sleepers) to be 3 feet apart, the heaviest weight they would have to bear would be when the driving wheels of the largest locomotive in use were resting on them, which would be equivalent to a weight of about 10 tons on the pair of rails, or 5 tons on one acting at the middle of the rail, equivalent to double that weight uniformly distributed. Considering the rail then as a girder, the strain on the lower flange $= S = \frac{W\,l}{8\,d} = \frac{10 \times 3}{8 \times \cdot 4}$ (making the depth $d =$ 5 inches) $=$ 10 tons nearly, and taking the safe strain as 4 tons per square inch, the sectional area of either flange of the rail should not be less than 2½ square inches, or of the whole rail, about 7 square inches. It is generally much more.

As a general rule, it may be stated that the *weight of a yard of rail, if supported at intervals, should be* 15 *lbs. for each ton of the greatest load on one driving wheel.* When the bearing is continuous, about five-sixths of that weight are sufficient.

The Permanent Way in use on the East Indian Railway, is formed of a double-headed rail, 84 lbs. to the yard, mostly in lengths of 20 feet. Six sleepers are used to each 20 feet length, being placed 3 feet 6 inches from centre to centre, except at the ends, where the bearing is 2 feet 6 inches from centre to centre of chair. The chairs used weigh 22 lbs. The gauge is 5 feet 6 inches, which is the gauge of all the Indian lines. On a portion of the Madras line, the same heavy rails as on the East Indian were used; on another portion, however, the road is laid with rails weighing only 65 lbs. to the yard, seven sleepers being used to a length of 20 feet. On the Madras line a plan was resorted to, which had been long since abandoned in England, of using granite blocks instead of sleepers; but, as might have been expected, their use was soon given up, owing to the blocks fracturing and the road being rendered rigid.

The following is the specification for the Jubbulpore Branch of the E. I. Railway now under construction :—

The weight of the permanent way is estimated to be as follows, per mile :—

115 tons rails of 73 lbs. to the yard.
Maximum length of a rail, 24 feet.
35 tons chairs 24·5 lbs. each.
5 tons fishes.
3 tons spikes, in cases of about 5 cwt.
1½ tons bolts and nuts, in cases of about 5 cwt.
1½ tons of keys, in casks.

The sleepers generally will be of Indian woods, 10 feet long and 12 inches by 6 inches in section, not exceeding 1,700 to the mile, and averaging about 240 tons weight to the mile ; but should it be found impossible to obtain a sufficient supply of native sleepers for the line between Allahabad and Myhere, creosoted fir sleepers, weighing 142 tons, or Greave's bowl sleepers, weighing 142 tons per mile, will be provided.

In laying rails, the allowance for the elongation produced by summer heat must be very carefully made. In a 15 feet rail, the difference of length for an increase of 76° Fahr. will be about $\frac{1}{11}$th of an inch ; but at the same time that provision must be made for the free expansion of the rails, they must not be laid with so open a joint as to give rise to concussions. It is usual, also, to give a slight inclination to the upper surface of the rails, inclining inward about 1 in 30, for the purpose of giving a better bearing to the conical surfaces of the wheels. Upon level crossings, very sharp curves, viaducts, or bridges, it is usual to fasten counter-rails; but they have so often proved sources of danger, through their independent movements, that these counter-rails are never placed unless under very exceptional circumstances. On level crossings they are necessary in order to protect the rails from the shocks of passing wagons.

Fractures of the rails occur on changes of temperature, and chairs are frequently broken when wedged up too tightly. Great care is therefore required in the inspection of the rails at these seasons; and it is worthy of remark, *that there is a marked tendency of the rails to displace themselves in the direction of the movement of the trains, especially on inclines and near the stations.* In some cases, every 10th or 20th rail is notched upon its chairs, in order to resist the tendency to this kind of displacement.

The following were the directions to the contractor for laying the permanent way on the Jubbulpore line:—

The centre line of the railway will be marked out by the Engineers, and stakes driven at proper intervals, giving both the line and level of the rails.

The sleepers are to be prepared for the reception of the chairs by planing the seats for the chairs for the whole breadth of the sleepers, and not less than 18 inches in length for each chair. The surface to be dressed smooth, level, and brought out of winding by means of gauges prepared for that purpose.

The joint sleepers and their chairs are to be first laid down, and the rails fished and laid in their places exactly parallel and level, and to the right gauge. The intermediate chairs having been previously slipped on to the rails the intermediate sleepers are then to be brought into their proper position, the chairs keyed on to the rails at the exact distance required, holes bored in the sleepers with the self-adjusting guard auger, and the spikes carefully and firmly driven and fixed.

There will be an average of about 1,700 sleepers laid in every mile of the railway, but plans will be furnished to the contractor showing their exact distance apart from centre to centre, and other necessary details.

The sleepers and rails are to be laid to the proper height at first, and no raising or lifting through the ballast will be permitted.

If necessary the ends of the rails are to be cut or filed true and square, and, in laying, all the joints must be left wide enough to allow for expansion.

226. *Permanent Way on Curves.*—In order to diminish the danger as far as possible of the carriages leaving the rails, it is usual in order to counteract the centrifugal force to give a transverse slope to the surface of the rails of a curve, technically termed the *cant.*

Let v be the velocity of a train in feet per second, moving round a curve of the radius r in feet, then its *centrifugal force* bears to its weight the proportion of

$$\frac{v^2}{32 \cdot 2r} : 1; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and this is the ratio which the *cant*, or elevation of the outer above the inner rails, must bear to the GAUGE, or transverse distance between the rails.

If V be the speed in miles an hour,

$$\text{cant for centrifugal force} = \text{gauge} \times \frac{V^2}{15r} \text{ nearly.}$$

One-half of the cant should be given by raising the outer rail above the level of the centre line, the other half by depressing the inner rail. It is impossible to adjust the cant alike for all speeds ; but it is best to adapt it nearly to the highest speed of ordinary occurrence on the line.

For example, suppose that speed to be 40 miles an hour; then the values of the cant for the centrifugal force, in inches are as follows, for different gauges :—

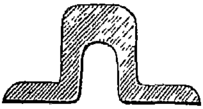
Gauge.	Cant for centrifugal force, in inches.
4 feet $8\frac{1}{2}$ inches.	6,000 ÷ radius in feet.
5 „ 6 „	7,040 ÷ „

A very common elevation of the outer rails, on curves of 1,000 yards radius (and this seems to be the minimum radius which should be allowed in railways upon which ordinary express speeds, are attained) is about 2 inches; and in curves near stations, of 500 yards radius, the elevation becomes about $2\frac{1}{3}$ inches.

Besides the danger from centrifugal force there is also a loss of power in passing round a curve, which is chiefly owing to the wheels on the outer rail of the curve having a larger arc to move over than those on the inner rail, whereby the resistance of the latter is greatly increased. To lessen this resistance, the wheels are made conical with their inner diameters greater than the outer, so that on curves the outer wheels run on their greater diameter and the inner ones on the less. This arrangement has, however, the disadvantage of increasing the oscillation of the carriages on straight lines.

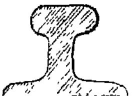
227. Having now considered the details of the most usual form of permanent way, we may consider one or two of the more important variation from the common practice. The first of these is the kind employed by Brunel for the Great Western Railway.

The gauge of this line was made 7 feet, instead of the ordinary one of 4 feet $8\frac{1}{2}$ inches, which of course involved heavier carriages, and therefore a greater weight to be borne by each rail. It was therefore resolved to support each rail along its whole length by sleepers fixed longitudinally instead of across. A rail weighing 72 lbs. to the yard was used, of the section shown in the figure, and was spiked down to the sleeper, without the intervention of chairs.

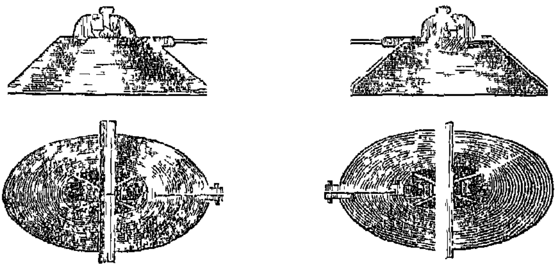


The great objection to their use lies, in the necessity they involve for a very expensive timber substructure, which is liable to rapid decay, and to frequent deformations by the warping of the wood, or by the expansion of the rails. Practically, then, although the system of continuous bearings produces a road of a very pleasant description for the traveller, so long at least as it is in order, it is found to be of so costly a maintenance that it is rarely used in England, unless when the roadway has to be carried over viaducts, bridges, or other works, where the percussion upon the intermediate bearings might become injurious.

For light or temporary Railways, *flat-bottomed* or *foot*, or single headed Rails are used, weighing only 30 or 40 lbs. to the yard. This kind is being used by the Indian Branch Railway Company in the lines now under construction, the speed on which is not to exceed twelve miles an hour, the gauge being only 4 feet.



The expense of Kyanising or Burnettizing wood, and the perishable nature of the material, even when so prepared, has led to the partial introduction of iron sleepers both in India and elsewhere. The objection hitherto made to them (besides their expense) has been the too great rigidity of the roadway thus formed, but of late years opinion seems to have altered on this point. On the Egyptian Railway they are in use, laid in sand-ballast, and are said to answer well, and a large number of Greave's patent have lately been sent out for the Punjab line. These consist of a combined cast-iron hollow block and chair in a single casting, the rails being fixed in the usual manner, and the gauge preserved by ties to each set of sleepers, as shown in the figure.



The cost of Greave's iron pot sleepers per mile on the Punjab Railway, as compared with wooden sleepers, is shown below :—

Cost of sleepers per mile on a line of single Railway—	£
Greave's iron pot,	1,500
Creosoted fir from England,	1,372
Creosoted Indian woods,	1,101
Sál,	1,085
Burmese iron-wood,	1,532
„ teak,	1,532
West Australian jarrah,	1,372

There appears to be some difference of opinion amongst Engineers as to the efficiency of this kind of permanent way. If the bowls are not laid in ballast of a soft and yielding nature like sand, they are apt to be broken by the concussion of passing trains. But on the whole they seem well adapted for Indian use especially at moderate speeds, while the indestructible nature of their material makes them far preferable to a line laid with wooden sleepers.

Cast-iron sleepers were experimentally used for a length of about 17 miles on the East Indian Railway; they were found to make such a rigid and bad road, that they had to be removed, and wooden sleepers substituted. The Chief Engineer then suggested the trial of a road entirely of wrought-iron, and Government sanction was obtained for an experimental length on one mile. This mile was laid down on the main line near Howrah, but with what result has not yet been published. The road is an ordinary bridge or foot rail on a longitudinal wrought-iron bearing, designed and patented by the Chief Engineer in 1859—and if it has proved successful, will probably be used for the doubling of the line.

228. The following is a description of this Permanent Way patented by Mr. Sibley:—

The wrought-iron road consists of a lower continuous bearing, formed by two angle-irons 5½ × 5½ in 20 feet lengths bolted together, breaking joint at half the length, and carrying a bridge rail bolted to the angle-iron longitudinals with ½ inch hard wood packing intervening. The cross transoms or ties being placed at 10 feet intervals, also formed of angle-iron, and bevilled at the end to give the necessary tilt to the rail.

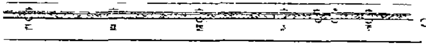
Five miles of this road have been down for the last two years on the E. I. Railway, and are said to have answered well. The cost is not more than that of the wooden sleeper road.

The advantages of this road are *first*, that it contains no perishable parts except the hard wood packing, a trifle in itself, which can be re-placed without disturbing the road.

WROUGHT-IRON ROADWAY

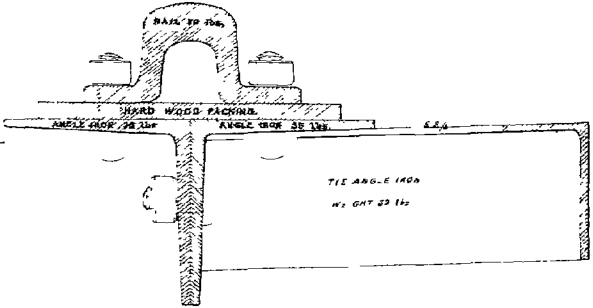
As designed and patented by Geo Sibley, Esq., C.E.

ELEVATION

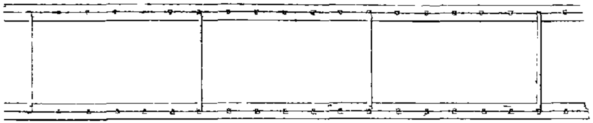


Scale [illegible] feet - 1 inches

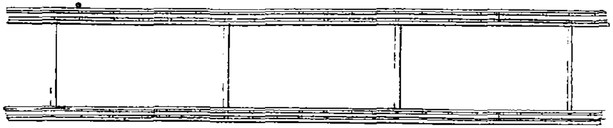
SECTION ONE-FIFTH OF FULL SIZE



PLAN OF UNDERSIDE



PLAN



Scale, 10 feet = 1 inch

Secondly, its great strength and stiffness, forming as it does a beam 9 inches deep, and 11 inches broad.

Thirdly, its great hold of the ballast, the central web being 5½ inches deep, which keeps it firmly in line even in curves.

Fourthly, the facility afforded for packing without opening out the road as is necessary with the sleeper road; and

Fifthly, the diminished depth of ballast required, owing to the bearing surface being only 3 inches below rails.*

A few years ago, a patent was taken out in India, by Mr. Rutter, for what he called the longitudinal block sleeper road, in which blocks of wood were shaped to receive the rail, and in which it was imbedded. The blocks were in pairs of any length, and were bolted together underneath the rail; the gauge was maintained by transverse tie-bars. This plan would perhaps be cheaper in India than the cross-sleeper road, but it has still the advantage of requiring timber. Mr. Rutter's invention is very similar to a plan proposed by Mr. W. Bridges Adams, in which a double-headed rail was enclosed in two longitudinal bulks of timber, which were tightly bolted below the rail. This system was tried on the North London and Eastern Counties line, and found to answer admirably. It was at one time proposed to introduce it on the Bombay and Baroda line.

229. Before proceeding further, the question of *Gauge* may be noticed; which, as explained already, means the clear interval between each pair of rails; the length of which is an important matter, as on it depends the width of all the rolling stock, and thence the weight of the various carriages.

The ordinary narrow gauge used in England and in many of the Continental lines is 4 feet 8½ inches, a dimension arbitrarily fixed from the fact of the first railways having been made at the collieries, on which the trucks then in use happened to be of the above dimensions. The same gauge was preserved on all lines for many years, until Brunel introduced the Broad Gauge (7 feet) on the Great Western Railway, calculating that thereby he would gain greater power, speed, and capacity of carriage, out of all proportion to the extra expense to be incurred. For the next few years the "battle of the gauges" was fought both in and out of Parliament; and it is now generally allowed that the narrow gauge advocates had the best of the argument; but, practically, the question was settled by the large number of lines which had adopted the narrow gauge, and from the extreme inconvenience attending a break of gauge at points of junction of two lines, and which necessitated an entire transfer of passengers and goods from one set of carriages to the other.

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* The consideration which determines the full depth of ballast required is the thickness provided below the bearing surface, this is fixed on our line at 14 inches in the sleeper road; the bearing surface is 13 inches below surface of rails, and the ballast is boxed up to within 3 inches of rail surface (giving a total depth of 2 feet), to preserve the sleepers from exposure, and to secure the road from lateral motion.

In the wrought iron road, the bearing surface is only 4 inches (instead of 13 inches as in a sleeper road) below surface of rails, thus effecting a clear saving of 9 inches, leaving the same depth below bearing surface.

The stability from lateral motion in the wrought-iron road is effectually secured by the deep angle-irons which have a 6 inch hold in the ballast.

On the Irish lines a medium gauge of 5 feet 3 inches was adopted, and that of 5 feet 6 inches was adopted after much discussion, as the gauge for all lines in India.

Railways may have either a single or double line of rails. Where the traffic is light, a single line will generally suffice, but ground should be taken sufficient for a double line, in case the traffic (as is likely) may hereafter require it. In India, the earthwork is made at first for a single line only, but the substructure of bridges is wide enough for a double line; that is in the case of an Iron Girder bridge on masonry piers, the piers are made of full length, but girders are at first only put up for one line.

Where a double line is used, one is reserved for the up, and one for the down, traffic, to avoid all chance of direct collision. On English lines the old rule of the road is observed, trains passing each other on the *right* of both; this is of course an arbitrary arrangement.

Where a single line is used, special arrangements have to be made to prevent risk of direct collision, but this will be more properly treated of further on.

230. To enable carriages to be transferred from one line to another, two methods are used. 1st, *Turntables;* these enable a carriage or engine to be turned round on the same line, or by being worked in pairs, and with the help of two short connecting rails to be moved from one line of rails to the other.

A Turntable is a large circular disc turning on a pivot, and of a size sufficient either to receive a carriage alone, or a locomotive, or an engine and tender. The turntables in general use are of cast-iron, with wrought-iron ties, bolts, and revolving gearing; they are also made of wood and iron, or of wrought-iron alone. Sometimes the whole table is supported on an iron girder, so nicely balanced on its pivot as to be easily turned by the strength of a couple of men. Large turntables are about 21 feet in diameter, the smaller ones 12 or 15 feet. Those for an engine and tender are, however, 40 feet in diameter. A turntable consists essentially of the following parts:—A foundation of masonry or concrete, a circular cast-iron base having a pivot in the centre, and a track for rollers round the circumference. A set of conical rollers carried in a frame which turns about the pivot; a platform supported on the pivot at its centre, and on the rollers at its circumference, carrying one or more lines of rails, and provided with catches to fix it in different positions. Turntables are generally moved by direct manual force, but those of the largest size require the aid of wheel-work.

If it be desired to reverse the direction of a train, and to avoid the expense of a turntable or to serve its purpose temporarily and there is sufficient space, two short siding lines may be laid in from the main line, diverging from it, but converging towards each other, and meeting at a short distance like the two sides of the letter V, with a piece of straight line continuing from their point of meeting, so that the whole resembles the letter Y. A carriage or train may be turned down one of these sidings, run along the piece of straight line to clear the switch, and then backed along the other siding into the main line, which it enters in the opposite direction to that in which it left it.

Traversing platforms are used when it is desired simply to pass engines or carriages from one line of rails to another situated parallelly to it. They are exclusively fixed in stations where no through traffic can possibly be admitted; because they consist of a platform susceptible of movement only in a direction transversal to that of the line of rails, and moving on rollers in a deep pit extending the whole length of the lines thus put in communication with one another.

Switches and Points.—By these, trains can be transferred from one line to another while in motion. The apparatus used consists of two parts known as the *switch* and the *points*, the former consisting of a moveable rail or tongue tapered at the end, so as to lie close to the main rail or to move sufficiently far to enable the flange of the wheel to go in between. To move the switches and render them also self-acting, a lever is employed with a counterpoise arranged to act within the switch-box, which is placed at the side of the line, and from which the handle of the lever protrudes.

The switches are arranged so that the main line is always kept open when the lever is not touched.

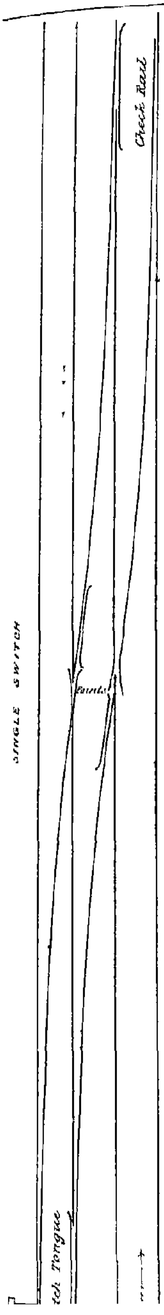
The *points* are fixed tapered terminations where two lines of rails cross each other, and which are made of extra hard iron or steel to prevent their being injured. Opposite the points *guard* or *check rails* are provided to keep the wheels from swerving out of the intended course.

In the plate, a *three-throw* switch is also shown. In this the single line of rails is shifted by the switch, which moves both rails together, to either of the three diverging lines.

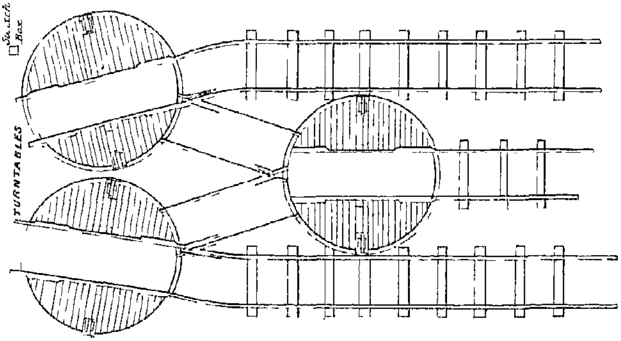
In estimating the amount of permanent way required for a line, a certain amount of *sidings* must be allowed for every station to enable a train to be *shunted*, *i. e.*, to be run off the main line when stopping at the station. An extra amount of ordinary rails and sidings must be allowed at more important stations where spare engines or carriages are kept, and a large additional amount for the terminal stations where trains are made up, spare carriages kept, &c., it being the first condition of safe traffic that the main lines are on no account to be blocked. Of this more will be said under the head of Stations.

PLATE XLIV

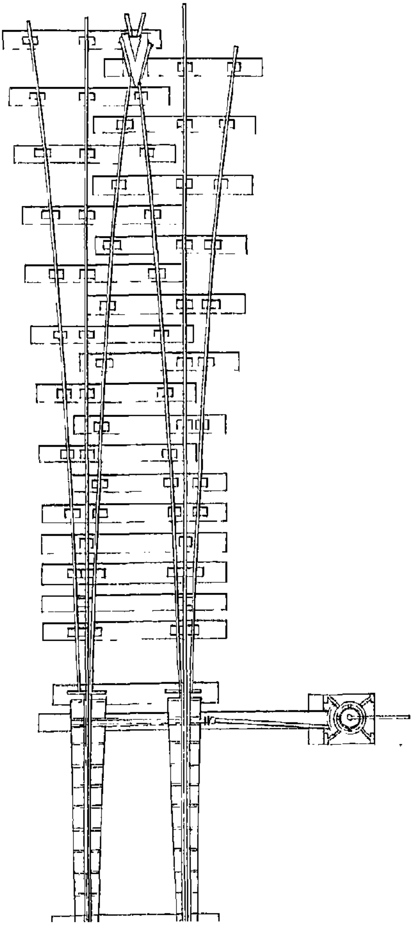
SINGLE SWITCH



TURNTABLES



THREE-THROW SWITCH



CHAPTER XLII.

ROLLING STOCK—LOCOMOTIVES.

231. *Rolling Stock.*—Railway carriages for the conveyance of passengers are usually very capacious, the bodies being made to project over the wheels, which in ordinary lines are made 3 feet, or 3 feet 6 inches in diameter; but as the centre of gravity of the carriages is kept very low, the oversailing of the frame produces no evil effects. On account of the rapid speed at which the carriages travel, and the violent shocks to which they are occasionally exposed, their frames are necessarily made of great strength; and every precaution is taken by the introduction of springs and buffers to diminish the violence of the blows they receive, or the effect they themselves might produce upon the rails. Elasticity in the traction is also necessary as well for the safety and comfort of the passengers, as for the preservation of the carriages; and even in order to economise engine power, for if it did not exist, the engine would be obliged to exercise a greater power to start the trains than it would do for the maintenance of the speed once attained. Various contrivances, more or less successful, have been adopted to secure these conditions; but the system represented in the plate is the one usually adopted; it represents the framework of a carriage, the body being supposed to be removed. The frame is carried on springs fixed outside the wheels, and resting on brass bushes, which bear directly on the axles: *a*, *a*, *a*, *a*, are the buffers, or discs of wood or metal, covered with cushions, and fixed to the ends of metal rods, working between guides against the ends of very strong horizontal springs *c*, *c*. In such cases, when the train is suddenly stopped, the springs are forced against one another, and serve thus to soften the blow to an extent dependent upon the force of the spring. The draw-bars are also attached to the centre of the horizontal springs, and thus prevent any sudden jar to the frames of the carriages at their starting, and the several draw-bars of a train are attached to one another by a coupling chain, bearing a double thread, so as to force the buffers into close contact; loose chains are also placed by the sides of the buffers, in case the coupling chains should break. Many varieties of springs have been applied for both the purposes described above; but experience has led engineers to resort to the old-fashioned plate springs, of course of considerable thickness, and of the very best quality of steel.

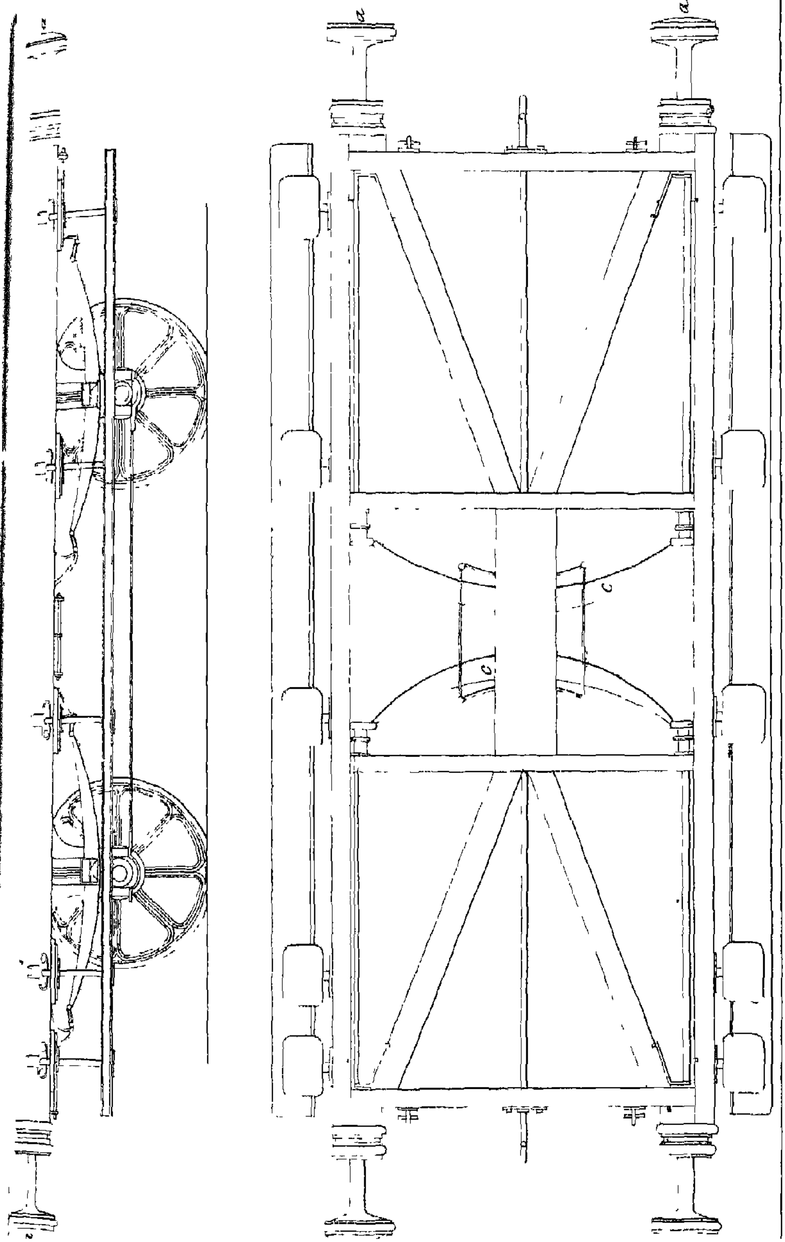
The ordinary first-class carriages have three compartments, able to contain from six to eight passengers in each compartment; the second-class carriages mostly have three or four compartments with ten passengers in each compartment; whilst the third-class carriages are made to contain from fifty to sixty passengers each. The weight of the best modern first-class carriages, on the narrow-gauge, is about 5¼ tons; that of the second-class is about 6¼ tons; and that of the third-class 6 tons: or, in other words, the ratios of the dead weights of the carriages to the loads transported are, in the several classes, as 2·9 to 1; as 2·1 to 1; and as 1·6 to 1. A certain number of the carriages in each train is made with breaks, and a guard's van, with occasionally an extra luggage van, are added. Horse-boxes, carriage-trucks, and post-office wagons are made upon the same principles of framing and suspension, as the ordinary traveller's carriages, so as to allow of their being added to the same trains as the latter. As the goods wagons do not travel at the same velocity as the wagons for the conveyance of passengers, there is not the same attention paid either to their modes of suspension, or to their draw-bars; but every wagon which is added to a train moved by a locomotive engine is hung upon springs, even when there is no spring draw-bar; there is very rarely any buffing apparatus attached to merchandise wagons. On ordinary narrow-gauge lines the weights of goods carriages range between 3 and 5 tons; they carry about 5 tons each.

On the American and some continental lines, the passenger carriages have no partitions but are open their entire length with a passage down the centre. Third class carriages are sometimes built in two tiers, to save expense; the height is apt to make them top-heavy at high speeds, and to necessitate greater space under any over-bridges crossing the line; they have however, been tried on the Bombay and Punjab lines, and are said to answer well.

Breaks consist of pieces of soft wood (poplar is generally used) which by means of a lever can be made to press against the circumference of the

PLATE XLV.

CARRIAGE FRAME.



wheels, and thus by the friction check their revolution, and bring the train to a stand still.

Proportion of Gross to Net Load.—The proportion of the weight of carriages to the weight which they can carry is important, as on it depends much of the economy of the traffic. In the following statement the ordinary proportion of the weight of goods and mineral wagons to the loads which they carry, are given on the authority of Mr. D. K. Clark ; and from those proportions are deduced the proportions of gross to net load in goods and mineral trains :—

	Wagon ÷ Net Load	Gross Load ÷ Net Load
Well made open wagons, ...	½	1½
Well made covered wagons, ...	¾	1¾
Clumsy wagons, ...	1	2

In computing the gross load to be drawn behind a locomotive engine which has a tender, the weight of the tender (from 10 to 15 tons) is to be added to that of the wagons and their load.

Passengers without luggage may be estimated at about 15 or 16 to the ton, and with luggage, about 10 to the ton (but this last is an uncertain estimate). In a passenger train the gross load may be roughly estimated at about three times the net load, with carriages suited for high speeds, weighing when empty 5 or 6 tons for a carriage capable of carrying 20 or 30 passengers. In light carriages on horse-worked railways the gross load need not exceed double the net load.

232. *Locomotives.*—The engines used to draw carriages on railways are generally known as locomotives. They are of various sizes and power, but the general principles of construction are the same and they differ only in details. It would be out of place here to do more than give a brief description of their construction and working ; for further information the student is referred to the many excellent treatises on the Steam Engine now available.

Locomotives have six or eight wheels; the two large ones, which are directly acted upon by the piston rods, are termed the *driving wheels*, and are from 5 to 8 feet in diameter.

Most engines have a pair of driving wheels in the centre, between two pairs of smaller wheels, 3 or 4 feet diameter, or two pairs of driving wheels placed together either before or behind the smaller pair. When extra power is required, as in goods engines, the driving wheels are *coup-*

led together, by *coupling-bars*, by which the action of the piston-rods is more directly transferred to the second pair of wheels.

Power in a locomotive is obtained by using steam of a higher pressure; *Speed* by using a greater quantity of steam within a given time; for each of these arrangements, therefore, a difference in the details of construction is required.

The fuel used in England is now generally coal. Coke, though giving out more heat with less bulk, is apt to injure the boiler tubes by its hard particles being driven into them, and the extra heat does not compensate for the extra cost of coking the coal. Coal is also used in Bengal; but in the N. W. Provinces and the Punjab, and elsewhere, where coal is not available, wood has to be employed instead ; this also necessitates certain changes in the construction of the locomotive.

233. Longitudinally the locomotive is divided into three parts, the *fire box*, which is behind, and in which the furnace is situated; the *boiler* in the centre, where the steam is generated; the *smoke box* in front, in or outside of which are the cylinders by which the steam is used to drive the pistons and connecting rods to give motion to the driving wheels. Above the smoke box is the funnel through which the smoke escapes and in which is the blast pipe, by which rapidity in combustion of the fuel and production of steam is secured.

The size of the firebars or grating must be adapted to the description of fuel used, whether wood or coal, and whether slow or fast burning.

Through the boiler, which occupies the principal mass of the engine, run a great number of small brass tubes, and through them the flame and heated air pass from the fire-box to the chimney. The tubes are about 6 feet long, 2 inches in diameter, and from 90 to 120 in number. They have been made 300 in number, and 1½ inches in diameter. By this contrivance, and by surrounding the fire-box with a double casing, containing water, all the heat is absorbed by the water before it reaches the chimney.

The introduction of the tubular boiler tripled the evaporating power of the engine, and caused a saving of 40 per cent. of the fuel. But the abstraction of all the heat from the air, destroyed the draught of the chimney, and therefore the activity of the fire. This evil seemed insurmountable, in spite of the use of fanners, till George Stephenson used the waste steam, which passed from the cylinder after working the engine, to create an artificial draught, by discharging it into the chimney, through the *blast pipe*. This steam blast has been termed the life-blood of the locomotive.

On the evaporative power of the boiler or the superficial area which can be at one time exposed to the heat, depends the speed of the engine.

The *cylinders* may be in or outside the smoke box, and in a horizontal or oblique position. By placing them inside heat is economized, as none of their steam is condensed by the cold atmosphere. In this position, besides being nearer the centre of resistance, they act with a less injurious strain; although, two pistons being necessary to pass the "dead-points" of the crank, their action is unvoidably unequal on each side in turn. But this arrangement gives less room for the machinery, and renders necessary a double-cranked axle, which is consequently much weakened, though cut from a solid mass of iron. Both the outside and inside arrangements have their advocates. The length of stroke of the piston, and diameter of the cylinder, bear a certain proportion to the evaporative power of the boiler, as the one should use the steam as fast as the other makes it. On these three dimensions depend the power and speed of the engine.

The connecting rods are either connected directly with the driving wheel if the cylinders are outside, or when they are inside they are connected with the cranked axle on which the driving wheels are keyed.

The feed pumps for the boiler are close to the cylinders, and are connected by a suction pipe with the tender in rear.

Behind, within easy reach of the engine driver, is the handle of the regulator by which steam is turned on or off, through the steam pipe; a lever at the side, by which as it acts on the eccentrics, the engine can be made to go forwards or backwards; a steam whistle by which signals or warning can be given; and a smaller lever, close to the eccentric lever, by which the communication between the feed pumps and the tender can be cut off or put on.

The *tender* conveys fuel and water for the engine and is immediately behind it. By a lever the break can be worked when a stoppage is necessary.

In what are called *tank engines*, the engine and tender are in one; they are used for short journeys, but are objectionable generally as bringing greater weight in a shorter length upon the rails.

234. The American locomotives, which are very similar to those used in this country, are of two kinds, which are universally adopted in the United States

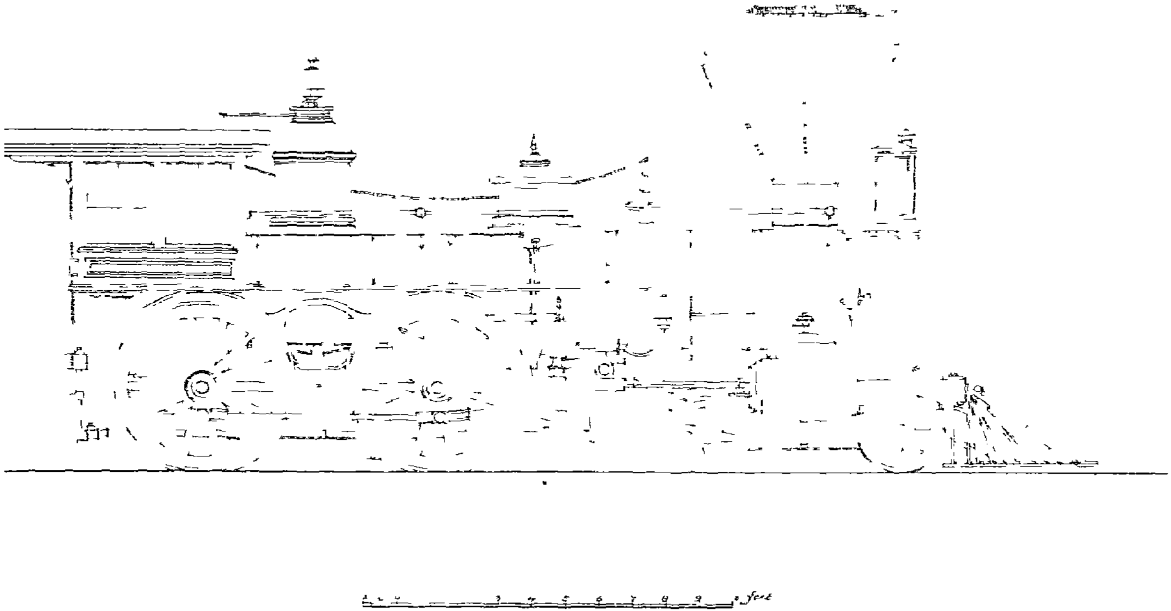
The passenger-locomotive has eight wheels, of which four in front are placed in a moveable frame, called a "bogie" or "truck," which swivels on a central pivot, and adapts itself to the curves of the lines; the four wheels behind are the "drivers;" they are larger than the front wheels, and of equal size and coupled. The cylinders are placed outside, just over the truck, horizontally. A "cab" or "house" is placed upon the hinder part of the machine, behind the boiler, for the protection of the engine-driver and the stoker from the weather, with ample glazed opening, to afford a clear view ahead. The chimney or "stalk" is in form externally like an inverted cone, expanding upwards; internally, it is cylindrical, and the space between the outer and inner chimneys forms a reservoir for cinders and ashes thrown up through the inner chimney, which are deflected by a baffle-plate at the top, and thrown over into the reservoir, trap, or "spark-catcher." This contrivance is specially designed for the use of wood as fuel, and to prevent the risk of conflagration arising from the numerous sparks which would otherwise be discharged in passing through forests and other ignitable districts. As a further precaution for the prevention of sparks, the top of the stalk is covered with a fine wire-net. The steam-whistle is situated above the boiler for ordinary use; and the bell is hung near to the cab, with ropes within reach of the engineman. The bell is used in passing through the streets. The cow-catcher is hung in front of the engine, to ward off stray cattle, &c., and the American flag is hung behind it. The tender is carried on eight wheels, disposed under two trucks, fore and aft, to facilitate the turning of the tender on the curves. The goods-locomotive is placed on ten wheels, of which six are coupled, to supply driving-power, and the leading four wheels are hung in a swivelling truck.

235. An ordinary passenger-locomotive of the present time weighs 19 to 23 tons, and occasionally as much as 27 tons, which is excessive. A goods-locomotive of the most powerful stamp weighs 27 to 32 tons, distributed on six-coupled wheels. Tenders weigh from 10 to 15 tons, with fuel and water supply. Tank-locomotives, or such as are constructed to carry their supply of fuel and water in reserve, without the aid of a tender, weigh a few tons heavier than the same engine if fitted with a tender. But tank-locomotives are usually made of small size, to work light, branch

PLATE XLVI

WOOD-BURNING PASSENGER LOCOMOTIVE

As used in America



traffic, and weigh lighter in consequence than most other engines—from 12 to 20 tons gross

Passenger-locomotives are commonly made with cylinders 15 or 16 inches in diameter, with a stroke of 20 to 24 inches, and driving-wheels varying from 5½ to 7 feet diameter, according to the duty for which the engine is made; for high-speed express trains the larger wheel is used. The cost of a modern passenger-locomotive and tender is about £2,300.

Ordinary goods-locomotives have cylinders 16 inches diameter, and 24 inches stroke, with 5 feet wheels. They cost about £2,800, with tender.

The fire-grates are 3 feet to 4 feet in length, and about 3 feet 6 inches wide; and the boilers contain 150 to 230 small flue-tubes, about 2 inches in diameter, and 10 to 11 feet in length.

236. The following was the Chief Engineer's specification for the locomotives to be used on the Punjab railway:—The locomotives sent out should be adapted for burning wood. They should be light also, which tends to decrease the wear of permanent way. This involves engines of less power than those now generally made in England; but our line is so level that such powerful engines are not required. Forty locomotives will work the line. Twenty 6-wheel engines, leading and trailing wheels 3 feet 6 inches diameter, driving wheels 6 feet, 12-inch cylinders and 20-inch stroke, weight not exceeding 20 tons; and twenty 6-wheel engines, leading wheels 3 feet 6 inches diameter, driving and trailing wheels 5 feet diameter, coupled, 14-inch cylinders, and 20-inch stroke, weight of engine not exceeding 22 tons, in both cases, exclusive of tender, which should carry 1,200 gallons, on six wheels, 3 feet 6 inches diameter; each engine and tender to be provided with a light frame or roof covered with painted canvas carried on uprights from the engine frame and tender, respectively, the tender roof being higher than the engine roof, so as to work perfectly clear and to lap over each other 9 inches.

Every portion or part of each engine and tender in each set of twenty to be made from one template, so that any piece of an engine shall fit and be applicable to perform the same duty for any other of the set.

237. The *speed* of an engine depends, as said before, on the rapidity with which its boiler can generate steam. One cylinder full of steam is required for each stroke of each of the pistons. Each double stroke corresponds to one revolution of the driving-wheels and to the propulsion of the engine through a space equal to their circumference. Wheels 7 feet in diameter pass over 22 feet in each complete revolution. To produce a speed of sixty miles per hour, they must revolve exactly 200 times in a minute; and to effect this number of revolutions each piston must make double that number of strokes in the same time.

Work to be done by a locomotive.—We have already investigated the resistance to be overcome in a train whether on the level or an incline. But besides drawing the train, the locomotive engine has to overcome the resistance of its own wheels and axles, and of its own mechanism; and this being added to the resistance of the tender and train, gives the *gross resistance* of the engine, tender, and train. Various rules have been proposed and tried for computing the additional resistance for the engine.

The following rule is founded on the principal that the resistance of the engine consists of two parts; the first, being the resistance of the engine *as a carriage*, is the same with that of a train of the same weight; the second being the resistance caused by the strain on the mechanism, bears a certain proportion to the whole resistance of the engine and train, whether arising from friction, concussion, or gravity; and that proportion appears to be about one-third. This is expressed by the following formula for the gross resistance R in lbs., of an engine whose weight is E tons, drawing a tender and train whose gross weight is T tons, at the speed of V miles an hour, up a gradient whose sine of inclination is i.

$$R = (T + E) \cdot \left\{ 8 + \frac{V^2}{180} + 2987\,i \right\}$$

in which the first and second co-efficients are those due to friction, concussion, and velocity, and the third expression shows the resistance caused by the incline.

For a descending gradient, each term in i is to be subtracted instead of added.

The energy exerted by the engine per minute, in foot pounds, is the product of the effort or gross resistance in pounds and speed in feet per minute; that is to say,

$$88\ VR;$$

(one mile an hour being 88 feet per minute). The *indicated horse-power* is

$$\frac{88\ VR}{33000} = \frac{VR}{375}$$

Let A be the area of each of the two pistons of the engine, in square inches; p, the *mean effective pressure*, in lbs. on the square inch; c, the circumference of the driving wheels, in feet; l, the length of stroke of the pistons, also in feet; then

$$2pA = \frac{cR}{2l}\text{ ; and}$$
$$p = \frac{cR}{4lA}.$$

The *mean speed* of the pistons is $176\ l\ V \div c$.

The mean effective pressure of steam in the cylinder is regulated by the effort required to overcome the resistance, as shown by the formulæ and calculations just given. The pressure of the steam in the boiler exceeds the mean effective pressure in the cylinder in a proportion depending on the extent to which the steam is worked expansively, and various other circumstances. It usually ranges in practice from 80 lbs. to 140 lbs. per square inch above the atmospheric pressure. In some cases engines have been worked at a pressure of 200 lbs. per square inch. The most common pressures at present are from 100 to 120 lbs.

The *tractive force* of a locomotive must evidently be at least equal to the sum of the gross resistances found as above. This force however is in general limited, not by the power which the engine is capable of exerting —for that is almost always more than sufficient to draw any load that it ever has to convey—but by the "*adhesion*," as it is called, or force which prevents the driving-wheels from slipping on the rails.

The adhesion is equal to the weight which rests on the driving wheels, multiplied by a co-efficient which depends on the condition of the surface of the rails; being greatest when they are clean and dry, and least when they are wet and greasy, or covered with ice.

On an average, the adhesion of a locomotive engine may be estimated at about *one-seventh* of the load on the driving wheels; for by sprinkling sand on the rails when they are slimy, or if they are icy, directing jets of steam on them, it may in general be prevented from falling below that amount.

In order that the rails may be able to bear the load on the driving wheels without damage, it is considered advisable that the load *on each wheel* should not in ordinary cases exceed 5 tons = 11,200 lbs. According to this rule the limits of load on the driving wheels, and of tractive force, are—

		Load on Driving Wheels.		Adhesion.
(1.) For engines with	one pair of driving wheels, ...	10 tons =	22,400	3,200
(2.) „	two pairs of driving wheels, coupled,	20 „	44,800	6,400
(3.) „	three pairs of driving wheels, coupled,	30 „	67,200	9,600
(4.) „	four pairs of driving wheels, coupled,	40 „	39,600	12,800

Evidently the *available tractive force* of a locomotive engine in ascending a given inclined plane (which, as above said, must be at least equal to the resistance of the heaviest train that it has to draw), is to be found by subtracting from the adhesion that component of the weight of the engine which acts as a resistance to its ascent; that is to say,

If E denote the total weight of the engine;

q E, that part of the weight which rests on the driving wheels;

i, the sine of the inclination of the railway;

P, the available tractive force; then

$$P = \left(\frac{q}{7} - i\right) E.$$

The following example of the use of the above formulæ is worked out from one given by Rankine.

$$\left.\begin{array}{r}\text{Let weight of train} = 104 \text{ tons}\\ \text{weight of tender} = 10 \text{ tons}\end{array}\right\} \therefore T = 114$$

$$\text{weight of engine} = E = 20 \text{ tons.}$$

$$\text{velocity per hour} = V = 24 \text{ miles}$$

$$\text{Ascending gradient} = 1 \text{ in } 133{\cdot}3 \quad \therefore i = {\cdot}0075$$

$$\text{Then } R = \left(114 + 20\right)\left\{8 + \frac{576}{180} + 2987 + {\cdot}0075\right\}$$

$$= 4{,}502 \text{ lbs}$$

On a level i would disappear, and R would equal 1,501 lbs, showing that the resistance caused by the ascent of the gradient is three times that on the level.

If the engines have one pair of driving wheels, then the available tractive force $= P = (\frac{1}{14} - {\cdot}0075)$ 20 tons.

$$= 2862 \text{ lbs.},$$

showing that the engine would not be powerful enough to draw the train up the incline.

If on a level, $P = \frac{1}{14} \times 20$ tons $= 3200$ lbs., *i. e.*, the whole tractive force is available, and this would be ample, the resistance on the level being only 1501 lbs.*

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* If we work out this same example by the formula given at p. 229, and take 80 square feet as the frontage of the train, we get—

Resistance of train and tender on level = 1711 lbs., and of the engine = 414 lbs. Total 2,125 lbs, to which must be added $\frac{134}{133{\cdot}3} = 1$ ton for the additional resistance caused by the incline, forming a total resistance on the *incline* of 4365 lbs., a result which agrees very closely with the former calculation, though the resistance on the *level* differs considerably.

Circumference of driving wheel = 20 feet
Stroke of pistons, - - - = 2 „
Area of each,- - - - = 200 square inches
On the incline, mean effective per square inch = p = 56 lbs.
Mean speed of pistons = 422 feet per minute.
Indicated horse-power = 288.

But, as shown above, the power of the engine being limited by the adhesion would not suffice to draw the train up the incline, even with an increased pressure of steam.

238. The *consumption of fuel* by locomotive engines per indicated horsepower per hour, may be estimated as ranging from 3 to 5 lbs , and the evaporation from 7 to 9 lbs. per lb. of fuel. The whole area of heating surface in ordinary engines varies from 800 to 2,000 square feet; and the area of heating surface for each lb. of fuel burned per hour, varies from about half a square foot to 1½ square feet, and is on an average about one square foot.

The action of the blast-pipe gives to the locomotive engine the power of adapting its consumption of fuel to the work which it has to perform, within certain limits. Hence the rapid consumption of fuel by heavy and powerful engines, in ascending steep inclined planes, is to a great extent compensated by the saving which takes place in descending.

The number of miles run per annum varies very much with circumstances. An engine, when on duty, may perform a duty averaging 120 train miles per day, amounting to upwards of 37,000 miles per annum, excluding Sundays. But as a portion of the stock is always under repair, and a portion in reserve, it is safe to allow 50 per cent. of the total number as off duty, leaving 50 per cent. at work, which would reduce the average performance per engine of the whole stock to 18,000 or 20,000 miles per annum. The circumstances of many lines do not admit of such a high average mileage; and the gross average mileage run by each locomotive, passenger and goods, may be taken at 16,000 train miles per annum.

Besides the train-miles run by engines, which are in fact the only performance recognised from a commercial point of view, they run many miles unavoidably "empty"—that is, without a train; the proportion of the empty or unprofitable mileage being dependent on the exigencies of the traffic and the nature of the line. A line with locally heavy gradients must have "assistant" or "pilot" engines in readiness to assist the trains up the inclines, which usually have to return empty to the depôt; and in cases of special trains, empty engines are run to or from the train, before or after duty, according to the situation of the engine-depôt, as the case may happen.

There is another duty, of a passive description, which is imposed on engines—to stand "in steam," or with the steam up and the fire in good order, in readiness to act when required. Assistant engines necessarily stand thus many hours a day while on duty, and there is a certain consumption of fuel incurred in so maintaining the steam. Some railway companies therefore, for the purpose of placing the whole duty of the locomotive department on record, register the whole time of engines being in steam, also the empty mileage run, besides the time on active duty and the train-miles run.

CHAPTER XLIII.

STATIONS.

239. A very important part of the establishment of a railway consists in the erection of the intermediate and the end stations. The result of past experience seems to prove that it is by no means advisable to construct these buildings, at the first opening of a line, in a costly or a permanent manner; but rather that the true policy of a railway company is to purchase at once all the land that may be required, and only to erect the permanent buildings when the traffic has had time to develope itself. As a general rule, it would seem to be necessary to purchase an additional quantity of ground, beyond that which is required for the roadway, of about eight acres for a first-class intermediate station; and of about four acres for a second-class one; the terminal passenger station for a first-class railway will require an area of about 4 to 6 acres; whilst the goods station of such a line will require about 25 or 40 acres, and the repairing shops, carriage depôts, engine houses, coke ovens, may require at least 12 acres. It may be added that in a large passenger station at a terminus, as many as forty people are constantly employed; and in a large terminal goods station there are often as many as 140; on a first-class intermediate station there are usually about ten people employed, and on a second-class station only about four. It has been found that the average length of sidings for turn-outs and goods stations, on lines with a large traffic, is not less than from 12 to 15 per cent. of the whole length of the through way; and the expense of the station buildings has been found to be not less than £2000 per mile lineal of the distance between the termini, when no very costly or monumental buildings have been attempted. In all cases the embarkation and landing of passengers should be effected under cover, and the same remark of course would apply to goods; the passenger platforms should be finished at the level of the floors of the carriages.

The several points for consideration in the design and arrangement of railway stations are too various to admit of any minute classification. In their general features only can any resemblance be recognised, or any rules made applicable. And yet in this department, much depends on the Engineer's judgment, as much of the economical working of the line will depend upon his judicious choice and arrangement of the stations, and their several adjuncts. The nature and magnitude of the traffic likely to occur, and the peculiarities of site and locality for the intended station, involve the main considerations, and must determine most of the details required.

The site will be determined by the contiguity of the town or place to be accommodated, cost of land, &c.; and, besides these, the question of relative levels arises, and deserves most especial regard. Indeed, the commercial value of the stations may be said to be made or marred by the facility or the difficulty of communicating with the adjoining thoroughfares. Whether the station be above or below the neighbouring level, a similar amount of expense and trouble will be incurred in transferring the luggage, and of inconvenience in transferring the passenger traffic. In some cases, as where a railway is permitted to approach a town only upon a viaduct, this great difficulty is necessarily encountered, and must be provided for by the best expedients which are available.

If the level of the rails be only about 4 feet above that of the approach road, the difference is readily made up by steps for the passengers, while it offers convenience in transferring the luggage from the platform direct into carts and wagons. A few additional feet beyond this may be accommodated by extra steps, and by employing "shoots" or troughs inclined from the one level to the other; but if the merchandise usually carried be of a bulky and weighty character, the goods department is preferably removed to such a distance that an ascending approach road may be formed. Any difference of levels may be accommodated by this expedient, provided such a length of road can be obtained as will allow the ascent by an easy gradient: but as the goods department is in such cases necessarily removed further from the town, and from the passenger department, other inconveniences arise which it is very desirable to obviate. Where such approaches cannot be had, and the entire difference of level must be provided for in a very limited space, it becomes necessary to adopt mechanical means for raising and lowering the goods, and to provide stairs or steps for the passengers.

240. The terminus of a long line of railway comprises complete arrangements for carrying on a large passenger and goods traffic; and in its immediate vicinity it is necessary to provide means of repairing, and perhaps of constructing the locomotive engines, besides proper places for containing them, and arangements for supplying the requisite fuel and water.

The Station Plot will therefore generally contain, as separate buildings, the Passenger station, Goods warehouse, Workshops, and Carriage and Locomotive sheds. The latter should be at some distance from the other buildings, to avoid, as far as possible the annoyance of the noise, steam, and smell, which necessarily pervade the engine-house, and also the danger of communication in case of fire.

The Passenger station will contain waiting-rooms for passengers, separating the first from the second, and other classes, separate conveniences for each sex, booking offices, store-rooms for lamps, oil, grease, &c., rooms for clerks, &c., and also suitable apartments for refreshments. The Manager's, Engineer's, and other offices may also conveniently be arranged in the same building. If these various rooms be arranged on two sides of the main building, the intermediate space will conveniently contain the arrival and departure platforms, and should be roofed over with a wooden or iron roof, lighted from above, or as is now very general, by a roof of iron and glass. The platforms are 10 to 15 feet wide, covered with stone, brick, or asphalte, and about 2 feet 5 inches above the level of the rails, by which facility is given for entering and leaving the carriages, and also for loading railway trucks with carriages, horses, cattle, sheep, goods, &c. Several examples of iron roofing applicable to stations are illustrated and described in the quarto volumes of the Professional Papers of the Corps of Royal Engineers.

On approaching the station, two lines of rails diverge from each other, so as to bring them close against the platforms, one of which serves as the departure platform, having booking offices, &c., contiguous to it, and the other as the arrival platform, in the immediate vicinity of which the refreshment rooms are suitably situated. The space between the two lines of rails must be wide enough for three or more spare lines of rails, to hold carriages of all classes, horse-boxes, carriage-trucks, &c. Access from the main lines to these spare lines is obtained by one, two, or more rows of turn-tables, one of which should be placed across each of the extreme ends of the station, and another intermediate, so that first, second, or third class carriages may be conveniently introduced at any part of the train Switches may also be laid connecting these spare lines with the main lines, but they should be of such a kind that the tongues may be wholly removed, except when in use, otherwise the arriving trains will run against the points. The supports for the roof, whether of iron or brick, may be fixed in rows between the spare lines of rails.

The Goods warehouses, if adjoining the station, should be kept back from the line formed by the other buildings, so as to allow one or more spare lines between the warehouse and the main line. If this cannot be done, the turn-plates must be fixed upon the main line, which is found objectionable, as they are thus exposed to a constant and most destructive kind of wear.

241. The following rules as to station accomodation have been laid down for the Jubbulpore Line, now under construction.

Accommodation to be provided in the passenger building at the main engine changing station.

	Super. feet.
Booking office and station master's room,	300
Telegraph and signaller's room,	300
1st class waiting and refreshment room,	600
2nd class ditto,	300
Ladies' room (waiting and retiring),	300

The above to be included in the main building of the passenger range.

3rd class entrance and general way out, 15 feet wide each.

Luggage weighing room,	300
Gentlemen's washing and retiring room,	300
Lamp room, &c.,	300
Stores, &c.,	300

The above to be placed in the wings of the passenger range.

One platform in the main engine-changing station to be 20 feet wide, with a covering roof over it and the adjoining road, 35 feet 3 inches span in the clear. This roof to be carried on a clerestory, raised above the roof of the passenger range for free ventilation and escape of smoke, and to consist of an iron frame-work with such suitable covering (not exceeding 40 lbs. weight per square foot) as may be hereafter decided upon.

The roof over the platform to extend the whole length of the main station building and wings, about 200 feet. The opposite platform will also be 20 feet wide but will not be roofed over in the first instance, nor will the supporting walls of the shed be built.

Third Class Stations.

	Super. feet.
Booking office and station master's room,	300
Telegraph office and signaller's room,	300

The above to form the body of the building.

	Super. feet.
3rd class entrance and general way out, 15 feet wide each.	
Retiring rooms,	300
Lamps and stores,	300

Both the up and down platform to be 30 feet in width ; a verandah 15 feet in outside width to extend on one platform the length of the passenger range, and a waiting-shed to be provided on the opposite platform covering an area of 500 square feet.

In changing stations sufficient width between up and down platform walls must be given to admit of four roads and two walls to carry the platform shed roof.

In third class stations, sufficient width between up and down platforms to be given for two roads.

A chubootra and well and latrine to be provided at every station for the accommodation of third class passengers.

The roof of station buildings to be carried on stone or brick arched ribs, or wrought-iron girders, as may in each case be most economical. The covering to be of the most suitable local material.

The up and down platforms to be built each 600 feet long in the first instance, leaving space for their extension to 1,000 feet hereafter if necessary.

Standard Dimensions.

	Ft.	In
The gauge to be,	5	6
Ordinary width of rail to be reckoned at,	0	3
Minimum clear width between the tracks in all stations,	8	0
Minimum clear width between the tracks on the line,	6	0
Clear distance of platform wall from rail,	2	6
Projection of nosing of platform,	0	3
Height of passenger platform above rail level,	2	9
Height of good's platform above rail level,	4	0
Minimum clear distance from track to side of fixed structure on running line,	4	6
Minimum clear space between tracks and side of fixed structure in stations, excepting platform walls,	6	6
Minimum clear height for all over-openings above rails in centre of each line,	14	6
Minimum clear height for all over-openings above rail level, at a point 4 feet 3 inches measured horizontally from centre of each line outwards, to be,	13	0

The angle at the sides of all over-openings as formed by the tangents thus fixed may be rounded off by a curve of 3 feet 3 inches radius.

Goods' loading gauge for interchange of traffic to be settled to pattern.

	Ft.	In
Breadth from centre to centre of buffers,	6	5
Height of centre of buffer above rail for all rolling-stock to be hereafter constructed,	3	6

Passenger Carriages.

	Ft.	In.
Extreme width of body, ...	8	6
N.B.—In the drawing this is 10 feet 6 inches of roof, ..	8	10
Ditto ditto of steps, ...	10	0

Length between centres of wheels.

Carriages and wagons, maximum, ...	11	0
Minimum diameter of turn-tables, ...	15	0
The engine and tender to turn on turn-tables of diameter of	40	0

All carriages and wagons to have spring-buffers and draw-springs at both ends.

242. A plan is given of the Umritsur Passenger Station on the Punjab Railway. The material employed for the building is brick throughout; the outer surface being carefully dressed with very close joints. The roofs are of pucka terras on trusses of low pitch, except, those over the platforms, which are to be of galvanized corrugated iron. The floors are all of brick-on-edge, set very close, and dressed smooth. The timber employed everywhere is deodar, from the forests of the Punjab Himalayas.—(*Professional Papers*, No. 3.)

243. A view is also given of the Calcutta Terminus of the Eastern Bengal Railway, of which the following is a description:—

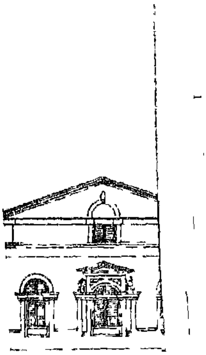
The building is in an Italian style of Oriental architecture, and is on a very extensive scale.

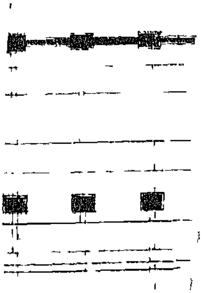
The two platforms are each above a 1000 feet in length and 27 feet wide. Three light wrought-iron roofs, each 615 feet in length, cover eight lines of rails. These roofs are painted internally light blue and white, and produce a very pretty effect. The span of each roof is about 53 feet.

The office accommodation for the Executive Staff is made very complete, and the waiting hall is of the following large dimensions, viz., length, 200 feet; width, 40 feet; height, 40 feet. The roofs over all the offices are flat and formed of wrought-iron girders and brick arches, which have a span of 13 feet; the bricks are 6 inches deep.

The upper parts of the roofs are covered with the ordinary *khoa* roofing, composed of broken brick, mixed with Sylhet lime, deposited in several layers, with plenty of water, the finest layers being placed uppermost, and the whole well beaten in the usual way.

The method by which the great waiting hall is lighted and ventilated is original. The chief light is obtained from a considerable elevation immediately above a lower corridor. It is admitted firstly through a series of arches pierced in the outer and inner walls of an upper arcade, which is built over the lower corridor. This arrangement obviates the necessity of using windows of any kind, since, during the rainy season, the water falls only in the upper arcade; but in cases of violent storms, when the rain beats at a very acute angle, "purdahs" or canvas screens are provided, which can be let down at pleasure.





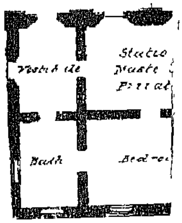
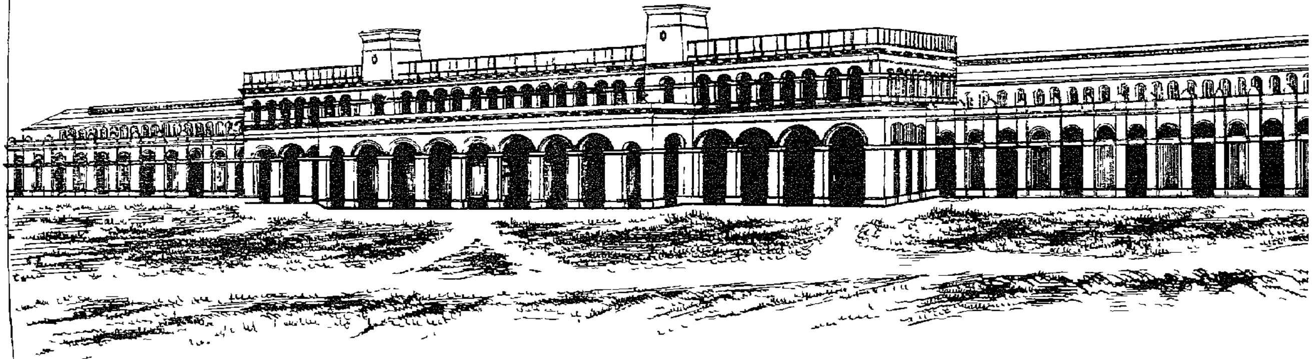

Vestibule
Studio
Music
Bath
Bed-ro

PLATE XLVIII.



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SEALDAH PASSENGER STATION,

EASTERN BENGAL RAILWAY

The following is a description of the Khooshtea station on the same line:—

Khooshtea is the terminal station of the first section of the Eastern Bengal Railway. It is situated on the south or right bank of the river Ganges, on a large open plain.

The station has two platforms, each 600 feet long and 19 feet wide, between which are four lines of rails.

The departure platform and two lines of rails are covered for a length of 300 feet, with a light and elegant iron roof, 47 feet span.

It is intended shortly to cover the arrival platform and remaining lines. In the centre of the building is a large waiting hall or booking-office, measuring 85 feet by 24 and 27 feet in height; it is approached under a good carriage porch. On either side are the respective rooms for the convenience of passengers and the executive staff, some of which are set apart as quarters for the station master.

The elevation of the whole has an imposing appearance, as the details are on a large scale. It has been designed in the simple Italian style, with numerous arches of the same charecter as that which has been adopted throughout the line.

There is a locomotive shed here for six engines, with the necessary coaling and watering appliances, and a very large goods-yard, with numerous sidings running to the river, and lines for a short distance parallel to the river bank, used for loading and unloading goods under a shed.

In Plate XV. is shown one of the 3rd class stations on the E. I. Railway.

244. *Watering Tanks.*—At certain stations, tanks are required from which the tenders may take in water for the engine. The distance that an engine can go without water will depend of course upon the work that it has to perform—perhaps 40 miles may be assumed as an average. The tanks are built in convenient places close to the station siding, and are provided with a syphon and hose for filling the tenders.

On the E. I. Railway, wells and bullock runs are employed, with an ordinary *chursa,* as shown in the figure; or a Persian wheel may be employed for the same purpose.

Gradient Boards are put up at the various changes of inclination, which are marked on both sides, as a guide to the engine driver to regulate the pressure of his steam according to the work to be done.

Signals will be treated of under the head of TRAFFIC.

245. The following returns are required by the Board of Trade, to be furnished previous to the opening of a new railway in England, and will be found generally useful.

I. A copy of the Parliamentary Plan and Section, with any deviation which in the construction may have been made from either, marked thereon in red; the corrections in the distances, levels, inclinations, sections of ground, and radii of curves, rendered necessary by such deviations, being also marked in red, as well as the positions of the several Stations. The width of Cuttings and Embankments on each side of the railway also to be marked on the Plan.

II. A table of Gradients and Level portions.
III. A table of Curves and Straight portions.
IV. A table of Cuttings and Embankments.
V. A table of the Bridges for roads crossed by the Railway.
VI. A table of the Bridges and Viaducts over Water-courses and Valleys.
VII. A table of Level Crossings.
VIII. A table of Tunnels.
IX. A table of Aqueducts and large Culverts.

According to printed forms, observing that the situations of works, &c., should be described in each by reference to the same fixed point; and that it will be convenient if the Station nearest to the Metropolis for a main line—and the junction with the main line for a branch Railway—be adopted as such point of reference.

X. A statement affording detailed information under the following heads:—

1st. *Permanent way.*—Whether the line be double throughout, or partly double and partly single, or single throughout with sidings; the distances from the fixed point adopted in the tables, at which the single portions commence and terminate—or, for a single line, at which the sidings commence and terminate—should be stated; whether the land has been purchased, or whether any other arrangements have been made with a view to adding an additional line at a future period; the width of the line at formation level; the gauge; the width between the lines where double; the description of rails employed, with a diagram section, their length, and weight per yard; the description and weight of the chairs; the mode of fixing the chairs, and securing the rails; the description of sleepers, with their smallest, and average, scantling and length; their distance asunder if transverse, their arrangement, and the details of any transverse supports or ties by which they are connected if longitudinal; the nature of the ballast, and its depth below the under surface of the sleepers; the description of switches adopted, with the name of the patentee, if they are patented.

The names of the stations are to be stated, at which engine turn-tables are provided.

2nd. *Fences.*—Description of fencing adopted on each portion of the line.

3rd. *Drainage.*—General description of the drainage employed, and if on any part of the line it has been attended with peculiar difficulty, a detailed description should be given.

4th. *Stations.*—Their names, and their distances from the fixed point, respectively, and the position of each marked upon the Parliamentary Plan.

5th. *Width of Line.*—The minimum space allowed between the sides of the largest carriages in use upon the railway, at the level of their windows, and any fixed works, such as bridges, pillars at stations, telegraph posts, sheds, &c., along the line.

6th. *Bridges and Viaducts.*—Drawings of all bridges and viaducts, either over or under the railway, in detail, accompanied by sufficient information to allow of the probable strength of each being ascertained by calculation.

XI. *Drawing and description of carriages to be used.*

MEMORANDUM OF IMPORTANT DESIDERATA AT THE STATIONS.—1. Platforms to be not *less* than 6 feet wide, at stations where the traffic is small; and the descent at the ends to be by means of ramps, and not by steps. Pillars for the support of roofs not to be nearer to the edge of the platforms than 6 feet.

2. Clocks to be provided in a position where they are visible from the line.

3. Signals and Distance Signals for each direction to be supplied.

4. The levers and handles of Switches and Signals to be placed in the most convenient positions, and to be brought close together, so as to be under the hand of the person working them. The switches to be provided with double connecting rods. The levers of the switches to be sufficiently long to enable the pointsmen to work them without risk or inconvenience, and not to be placed between the lines of rails.

5. No facing points, except on single lines, or at junctions, or in exceptional cases. At all junctions, the signals should be worked in connection with the points. In other cases a low signal should be attached to the points, to indicate to the driver of an approaching train whether they are set in the proper direction.

6. Sidings to be supplied with locked chock-blocks, and, if they fall towards the main line, a blind siding to be provided with the points closed against the main line.

7. Turn-tables for engines to be erected at terminal stations, and at junctions and other points at which the engines require to be turned.

8.—*As regards the Line generally.* For every Cast-iron Bridge the breaking weight should be equal to *three* times the permanent load due to the weight of the superstructure, added to *six* times the greatest moving load that can be brought upon it.

9. For every wrought-iron bridge, the greatest weight which can be brought upon it, added to the weight of the superstructure, should not produce a greater strain on any part of the material than *five* tons per square inch. The heaviest engines in use on railways afford a measure of the greatest moving weights to which the bridges can be subjected.

10. The upper surfaces of wooden platforms of bridges and viaducts should be protected from fire.

11. The joints of the rails should be secured by means of fish-plates, or by some other equally secure fastening.

12. On all curves the chairs should be secured, at least partially, by iron spikes. With rails known as contractors' rails, when there are no chairs, or with bridge rails, it is desirable that fang, or other through bolts should be used, at least at the joints.

13. No standing work above the level of the carriage steps should be nearer to the outer edge of the rail than 4 feet.

14. The intervals between adjacent lines of rails or between lines of rails and sidings, should be not less than 6 feet.

15. When Stations occur on or near a viaduct, a parapet wall on each side, 3 feet high, should be built, with a hand-railing or a fence on the top, sufficient to prevent passengers from falling over the viaduct in the dark. For the protection of the platelayers, viaducts under the railway should be guarded by a handrail. Viaducts of timber and iron should be provided with man-holes, and with facilities for inspection.

16. At all level crossings of turnpike, and of public roads, the gates should be capable of being closed across the railway on both sides as well as across the road; and a lodge or station-house should be provided.

17. The fixed signals attached to the gates should be placed at the level crossings in convenient positions for being seen along the railway as well as along the road, and when a level crossing is so situated that an approaching train cannot be seen from a sufficient distance, distance signals should be supplied.

18. At all junctions, main signals and distant signals for each line are required; and clocks should be placed in a conspicuous position for the use of the signalmen.

19. It is desirable that the signal-handles and levers of the switches at junctions should be brought together upon a properly constructed stage. They should be so arranged, that a signalman shall be unable to lower a signal for the approach of a train until after he has set the points in the proper direction for it to pass ; and that it shall not be possible for him to exhibit at the same moment any signals that can lead to a collision between two trains.

20. Mile-posts and gradient-boards should be provided along the line.

21. The junctions between the main line and any sidings which lead to ballast pits in use, or which are employed for colliery or other purposes, should be protected by a distance signal in each direction.

246. The following are some details of the Sindh Railway:—

The distance between Kurrachee and Kotree traversed by the Sind Railway is 108 miles 10 chains. Of this distance 32 miles 50 chains are level, and the remaining 75 miles 40 chains are on inclines more or less favorable, 1 in 200 being the ruling gradient.

The total length of straight line being 74 miles 22 chains, the length of the line on curves is, therefore, 33 miles 68 chains, the sharpest curve having a radius of 43 chains for a distance of 76 chains.

The earthworks generally are executed to accommodate a single line of railway; but all the bridges, culverts, and stone viaducts are constructed to carry a double line. In the cases of the wrought-iron viaducts, the stone piers are adapted to support girders for a double way, while those required for a single line alone are erected.

The Permanent Way consists of the ordinary double-headed rail, weighing 65 lbs. per yard, fixed by compressed wooden keys in chairs, each weighing 22 lbs The joints are fished in the usual way, the fish-plates being secured by four bolts, each 1 inch in diameter. The whole is laid on transverse wooden sleepers at intervals of 3 feet except at the joints, where the sleepers are only 2 feet apart. The dimensions of the sleepers are—length, 10 feet ; breadth, 10 inches; depth, 5 inches. A large proportion of the sleepers is of red and white pine creosoted, sent from England.

The remainder are partly of deodar from the Punjab forests, and partly of Australian blue and white gum, and native red cyne. These were objectionable, on account of their great weight, and the ease with which they were split by the driving of the spikes.

To protect the deodar sleepers from the attacks of white-ants, and before the Burnettising apparatus was received from England, they were steeped in a solution of sulphate of copper. This proved to be an unfailing specific ; but it possesses this serious objection, that iron nails or spikes driven into timber thus prepared are rapidly destroyed by the action of the sulphuric acid. The result of experience, with reference to the important question of sleepers, is that pine sleepers, whether red or white, imported from England and creosoted, are liable to split and twist to a great extent, probably on account of the extreme dryness of the climate. They also become very brittle, the nature of the timber being destroyed. The creosoting process only penetrates a certain distance from the surface of the sleeper; and so long as the sleeper does not split, the creosote effectually protects it from the attacks of the ant, but immediately a part of the interior becomes exposed, the ant attacks it, and soon destroys the uncreosoted core of the sleeper.

The excellent ballast on the Sindh Railway, consisting chiefly of broken stone or clean gravel, assists in preserving the sleepers from the white ant.

The majority of the Fencing used on the Sindh Railway consists of a dry rubble-stone wall, having a coping of stones on edge, set in mortar. Its height is 4 feet above the surface of the ground. Its thickness at the bottom, just above the footings, is 1 foot 10½ inches, and at the top 15 inches. Its average cost was 3*s.* per lineal yard. Along 15 miles of the line, between Jemedar-ke-Landi and Guggur, five-strand wire fencing was adopted on account of the distance of suitable stone, and the necessity for its rapid completion. Its cost was 2*s.* 4½*d.* per lineal yard. The cost of maintenance of the wire-fencing is high, compared with that of the stone wall.

247. The following refers to the G. I. P. Railway:—

The first section undertaken by the Great Indian Peninsula Railway Company was that from Bombay to Callian, 33 miles, with a branch to Mahim of 1¾ miles; it was called the "Experimental Line." The portion from Bombay to Tannah, a distance of 20 miles, was the first railway opened in India for public traffic, which event took place on the 16th of April, 1853. From Bombay to Callian, a double line of rails has been laid. Its steepest gradient is 1 in 150, and the radius of the sharpest curve is 40 chains.

The principal works upon the Experimental Line are the crossing of the Sion Marsh, which is effected by an embankment; the crossing of the arm of the sea from the island of Salsette to the Concan, comprising two viaducts, the length respectively, of 111 yards and 193 yards, in the latter of which there is an opening for navigation of 84 feet, spanned by wrought-iron plate girders; beyond this, there are two tunnels of the respective lengths of 103 yards and 115 yards. The railway is protected by post and rail fences, and prickly-pear and cactus hedges. The station buildings are of masonry. The permanent way is chiefly laid with transverse wooden sleepers, and 6 miles of it with iron pot-sleepers. The rails, which are of the double T form, weigh 84 lbs. per lineal yard, as far as Tannah; beyond which place, they weigh only 65 lbs. and 68 lbs. per yard. The lighter rails extend along the whole of the Company's main lines, except the two Ghaut Inclines, on which are laid rails of 85 lbs. per yard. From Callian diverge,—the South-Eastern Extension to Poonah and Sholapore, and its proposed prolongation to the river Kristna and the Madras Railway,—and the North-Eastern Extension to Nassick and Jubbulpore, to join the East Indian Railway from Calcutta, by which a communication will also be effected with the North-Western Provinces of India.

S. E. EXTENSION.—The first section of the South-Eastern Extension is from Callian to Campoolee, at the foot of the Bhôre Ghaut mail-road. It is 37¾ miles in length, of which 30¼ miles, to the foot of the railway incline, are permanent, the remainder having been designed for temporary use, until the Ghaut Incline was opened. This portion of the railway has been constructed for a double line, but only one road has been laid. Its ruling gradient is 1 in 115 on the permanent, and 1 in 85 on the temporary, portion. The radius of its sharpest curve is 40 chains. It contains no work of any special character, but it is remarkable for the extraordinary floods and rapid torrents to which it is exposed on both sides. The bridges and culverts are built of rubble masonry, with coursed facework; and in one or two instances, cast-iron girders were made use of. The average cost of this section, exclusive of rolling stock, was only £4,500 per mile.

Bhôre Ghaut Incline.—Four years were spent in preliminary surveys of this incline, and in laying out and preparing cross sections, to the number of about two thousand, and perhaps the most difficult that have ever been taken.

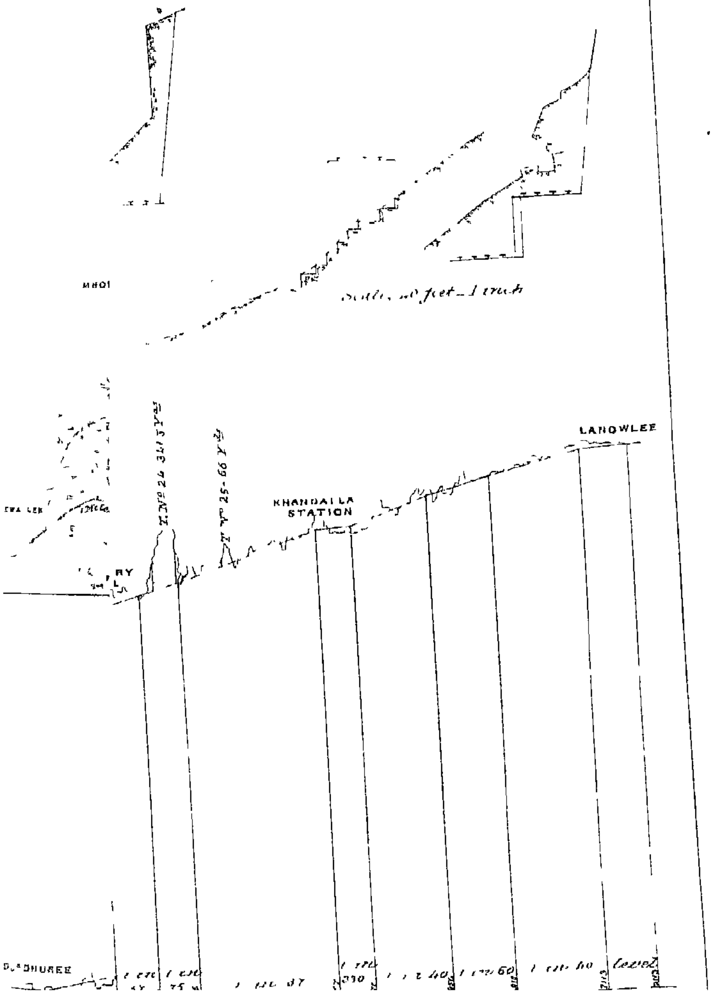
It is 15 miles 68 chains in length, and the total rise is 1,831 feet. Its average gradient is 1 in 48. The steepest gradients are 1 in 37, extending in one length for 1 mile 10 chains, and 1 in 40 for 5 miles 6 chains. Short lengths of level gradients and of 1 in 330 are introduced into this incline, to facilitate the ascent of the engine. The radii of the curves upon it range from 15 chains to 80 chains, and 5 miles 33 chains are straight. It comprises twenty-five tunnels, of a total length of 3,585 yards. The longest is 437 yards; and the longest without a shaft, which is carried through a mountain of basalt, is 346 yards. There are eight viaducts of a total length of 987 yards. The two largest are 168 yards long, and respectively, 163 feet and 160 feet above the foundations. The viaducts are being built, up to the surface of the ground, of solid block-in-course masonry, and above, of block-in-course facework, strongly tied through, by header bonds of block-in-course, to the internal work of sound rubble, and with coursed rubble arches. The contract also comprises a large quantity of retaining walls. The total quantity of cutting, chiefly rock, amounts, by calculation, to 1,263, 102 cubic yards. The maximum depth of cutting is 70 feet, and the greatest contents, 75,000 cubic yards of trap rock. The embankments amount to 1,849,934 cubic yards, the maximum height being 74 feet; and greatest contents are 209,000 and 263,000 cubic yards. The slopes average about 1½ to 1. There are twenty-three bridges of various spans, from 7 feet to 30 feet, and sixty culverts from 2 feet to 6 feet wide. The rails weigh 85 lbs. per yard, and are laid with fish-joints, with small cast-iron saddles under the joints, resting upon longitudinal planks, the ends of which bear upon, and are secured by fang bolts, to transverse wooden sleepers. The estimated cost of this incline is £750,000. The upper 2 miles from Khandalla to Lanowlee, with gradients of 1 in 40 and 1 in 50, were opened on the 14th of June, 1858, and have since been worked with safety and regularity.

At the eleventh mile, the incline is divided into two banks, by what is called a reversing station. This sub-division, however, was not adopted for the purpose of making two banks of the incline, but of increasing the length of the base, in order to flatten the gradient and to reach a higher level, where it encountered the great features of the Ghaut margin, near Khandalla. Without the necessary expedient of the reversing station, the practicability of changing the direction of the line would have been confined to making curves of small radius; but with the device of the reversing station, the direction was altered at a very acute angle, by means of points and crossings. In consequence of its adoption, the incline is prolonged by nearly the difference between the length of the two sides of an acute-angled triangle, and that of its base.

The next section of the South-Eastern Extension is from Lanowlee, the summit of

TH BHORE GHAT INCLINE.

Cross Sections



the Bhôre Ghaut Incline, to Poonah and Sholapore, and is 205½ miles in length. Its engineering character is very similar to that of the Concan section. Its ruling gradient is 1 in 132, and the radius of its sharpest curve is 40 chains. The cuttings are in trap rock, moorum, and soil; and the embankments are chiefly composed of soil and moorum. There are twenty-two viaducts three hundred and fifty-nine bridges, and four hundred and fifty-four culverts, all built of substantial masonry. The largest works are the viaducts over the Beema, 441 yards long and 60 feet high, consisting of twenty-eight segmental arches 40 feet in span, with a flood stream 46 feet deep, and rock foundations, the cost of which was £24,246; and that over the river Seena, 190 yards long, 54 feet high, consisting of twelve segmental arches 40 feet in span, with a flood stream 41 feet deep, and foundations partly in rock and partly on hard clay. The fences are dry rubble walls, and cast-iron posts and iron-wire rails. One peculiarity of this district is the violence and suddenness of the floods, which descend with scarcely an hour's notice, and gather into torrents on spots upon which there is no trace or warning of any stream. In the uncommenced portion of the South-Eastern Extension, from Sholapore to the junction with the Madras Line, in the Raichore district there will be two very large viaducts over the rivers Beema and Kristna. Upon the South Eastern Extension large quantities of cotton and country produce are now carried, and it is evident that an immense traffic must soon be accommodated. The earthwork has been executed for a single line, and the viaducts and bridges for a double line.

N. E. Extension.—Returning to Callian, the first section of the North-Eastern Extension, which there diverges towards Jubbulpore and Calcutta, is from Callian to Kussarah, 26 miles, gradually climbing, by steep gradients, of which a great portion are 1 in 100, the flank of a long mountain spur, which projects from the Ghaut range, and divides the valley of the Basta on the south, from the Wyturnee on the north. This section is full of heavy work; but to obtain even such a line, demanded a long and minute study of the rugged and jungle-covered district. The radius of the sharpest curve is 30 chains. It contains 520,493 yards of cutting, chiefly trap and basaltic rock, and 1,353,317 cubic yards of embankment. It comprises four viaducts, of which the two largest are respectively, 124 yards and 143 yards long, and 127 feet and 122 feet high; forty-four bridges from 7 feet to 30 feet in span, and one hundred and seventeen culverts. By means of this section, 849 feet of the ascent have been surmounted to the summit of the Ghaut, and thus the altitude to be overcome by the Thul Ghaut Incline is reduced to only 972 feet.

Thul Ghaut Incline.—The Thul Ghaut Incline extends from the village of Kussarah to Egutpoora, and is 9½ miles in length, having a total ascent of 972 feet. At the end of 3¾ miles there is a reversing station, similar to that upon the Bhôre Ghaut Incline, by which the base was lengthened, the gradient flattened, and the incline divided into two banks. The steepest gradient is 1 in 37, for a length of 4 miles 30 chains; and the same introduction of a level portion is adopted here as on the Bhôre Ghaut. The radius of the curves ranges from 17 chains to 100 chains, and 3 miles 28 chains are straight. There are 13 tunnels, of a total length of 2,652 yards. The longest are, one of 474 yards, in black basalt, with two shafts, and another of 483 yards, without a shaft, in greenstone. There are six viaducts, of a total length of 741 yards, the largest of which are respectively, 144 and 250 yards long, and 83 feet and 182 feet high. The latter is designed for three spans of triangular iron girders measuring 150 feet, with a pair of semi-circular abutment arches, measuring 40 feet at each end. There are fifteen bridges, of which the span varies from 7 feet to 30 feet, and sixty-two culverts. The cost of the incline will be about £450,000. The preliminary surveys and studies occupied four years, and the works were commenced in October, 1857.

The next section of the North-Eastern Extension runs from the summit of the Thul Ghaut Incline, at Egutpoora, by Nassick, across the fertile valley of the Godavery, and the Indhadree range of mountains, along Khandeish to Bhosawul, the point of junction with the Oomrawuttee and Nagpore Branch. The character of this line is very similar to the corresponding section of the South-Eastern Extension, from the Bhôre Ghaut to Sholapore, and the nature of the earthwork is much the same. The principal works upon it are—a viaduct over the Godavery, 145 yards in length, consisting of nine arches 40 feet in span, with a flood stream 36 feet deep, and foundations upon rock, excavated through sand; the Kadoo Viaduct, 242 yards in length, with fifteen arches 10 feet in span; the Mumair Viaduct, with five openings spanned by triangular iron girders, and two pairs of abutment arches; and the Waugoor Viaduct, with ten openings, also spanned by triangular iron girders. The section contains twenty viaducts, two hundred and seventy-nine bridges, and four hundred and thirty-five culverts.

The last section of the North-Eastern Extension runs from Bhosawul to Jubbulpore. It is 328 miles in length, and was contracted for by Messrs. Duckett and Stend, in January, 1859. As the operations are in a preliminary state, it is only necessary to notice the two very large viaducts over the rivers Taptee and Nerbudda. The Taptee Viaduct is 875 yards long, consisting of five openings of 138 feet and fourteen openings of 60 feet, and twenty arches 10 feet in span, with a flood stream 70 feet in depth, and foundations upon rocks. The Nerbudda Viaduct will be about 387 yards long, 100 feet high, with a flood stream 90 feet deep.

The Oomrawuttee and Nagpore Branch is about 263 miles in length. As the line has not yet been entirely staked out, no details can, at present, be given; but its general character is known to be favorable, and the works are light. The largest works will be the viaducts over the rivers Nalgunge and Wurdah.

There is no tunnel beyond the Ghauts, upon any of the lines now under construction, comprising a length of 782 miles.

CHAPTER XLIV.

TRAFFIC.

248. The arrangements for traffic are under the control of the *Traffic Manager*, subject, of course, to the orders of the Agent or General Manager of the line. It is his business to determine what trains are to run and at what hours, and to fix the tariffs. In India, however, all such arrangements are made in concert with Government, whose consent is necessary, as expressed through its Consulting Engineer.

The questions of fares for passengers and for the different classes of goods—of working expenses—of the rates of speed to be maintained, &c., &c., are very complicated, and depend upon a variety of considerations, which hardly come within the province of an Engineer to decide.

249. The following statistics for 1865-66, refer to the E. I. Railway, the most important line in India:—

The mean length of Railway open for traffic during the year ending 31st December, 1865, was 1,128 miles.

The line on the 21st December, 1865, was stocked as under:—

LOWER DIVISION.		UPPER DIVISION.	
Passenger engines, ..	55	Passenger engines, ..	37
Goods engines, ..	184	Goods engines, ..	46

Traffic vehicles of sorts, .. 5,547.

The gross earnings for the year, including Steam Ferry receipts, amounted to Rs. 1,84,45,976; the working expenses to Rs. 83,09,340; and the profits to Rs. 1,01,36,636.

The results of the year's working were very satisfactory, the expenses forming only 44·5 per cent. of the gross earnings.

Assuming the cost of the Railway to be Rs. 2,00,000 per mile, the approximate dividend amounts to 4·3 per cent. per annum.

Coaching yielded 36·8 per cent. of the entire traffic, and merchandize 61·3 per cent.

Coaching receipts per train mile were Rs. 4-5-0. Merchandize receipts per train mile were Rs. 4-6-3.

The total earnings per train mile were Rs. 4-4-6, and the profits Rs. 2-5-9. The gross earnings average £29 per mile of Railway per week.

The following Statement shows the goods traffic of the year by classes :—

Class.		Traffic in Goods.		Average mileage per maund
		Maunds carried.	Receipts thereon.	
		In 1865.	In 1865.	1865
			RS.	
First class, ...	up ..	45,84,818	21,97,040	316·3
	down	41,90,662	13,10,051	182·5
Second class, ...	up ..	17,12,607	19,57,204	411·5
	down	5,26,419	4,01,705	105 0
Third class, ...	up ..	3,31,686	4,01,863	362 8
	down	11,20,358	21,53,532	337·0
Fourth class, ...	up ..	2,69,158	6,28,171	360 8
	down	2,45,064	4,38,014	289 5
Fifth class, ...	up ..	34,322	1,48,298	412·3
	down	13,012	42,380	237 5
Special class, coal, ..	up ..	53,549	5,190	308·2
	down	5,29,597	87,093	335·5
Special class, goods, ..	up ..	5,76,202	2,11,499	90·2
	down	62,91,016	10,55,026	68·5
Total of all classes, ..	up ..	75,02,342	55,49,265	327·4
	down	1,29,19,128	57,87,801	221·5

The following table exhibits the Passenger traffic of the last two years by classes :—

The Passenger Fares are as under :—

	AS.	P.	
First class, ...	1	6	per mile.
Second „	0	9	„
Third „	0	3	„
Upon Third class between Howrah, Raneegunge, and intermediate stations only,..	0	4½	„

Classes.	Number conveyed.	Average mileage.	Receipts from Passengers.
	1865.		1865.
			RS.
First class, ...	32,369	126	3,87,710
Percentage of entire traffic, ..	0 8	...	...
Second class, ...	83,276	100	3,91,136
Percentage of entire traffic, ..	1·9	...	...
Intermediate and third class,	4,133,975	78	5,166,787
Percentage of entire traffic, ..	97·3	...	...

The traffic of the metropolitan section between Calcutta and Burdwan, 67½ miles, greatly exceeds the average of the remainder of the line.

250. In order to provide duly for the public safety, regulations are made from time to time, as to the minimum intervals at which trains are to follow each other, and as to the rates of speed to be observed; maximum rates being specially fixed for running round any severe curves on the line, which should on no account be exceeded.

It has been before observed that, in the case of a double line, one line is reserved for the up and one for the down traffic; the terms *up* and *down* being of course conventional. When a single line only is laid down, certain stations are appointed at which every train as it arrives, stops, and is *shunted*, until the train coming in the opposite direction has also arrived and passed it on the main line.

In order to work these and other arrangements which are essential to safety, a line of Electric Telegraph is required along the Railway, as also a proper code of *Signals*. All lines have their own bye-laws and rules for signals, but those now in use on English or Indian lines are pretty much the same.

Signals are either *moveable* or *fixed;* the former consist of flags by day and lamps by night, of different colors. *Red*, generally meaning danger; *green*, caution; and *white*, safety.

Fixed signals consist of semaphores, with arms of different colors, and which can be raised or lowered or fixed in different positions by levers worked on the spot, or by means of wires from the station a short distance off. These latter are called distance signals. There are also Fog or Detonating signals, used when the weather is thick.

251. The following rules are extracted from those in use on one of the most recently opened English lines:—

SIGNALS.—*Color.*—Red is a signal of danger, and to stop. Green is a signal of caution, and to go slowly. White is a signal of all right, and to go on.

Stop.—The signal to stop will be given by a red flag, disc, or light, or by the left hand side arm of the semaphore being raised to a horizontal position.—*Fig.* 1.

Go Slowly.—The signal to go slowly will be given by a green flag, disc, or light; or by the left-hand side arm of the semaphore being raised half-way up.—*Fig.* 2.

Go on.—The signal to go on will be given by a white flag, disc, or light; or by the left-hand side arm of the semaphore being within the post.—*Fig.* 3.

When both arms of the semaphore are raised, both lines are obstructed.—*Fig.* 4.

In the absence of regular signals, anything moved violently up and down, or a man holding both hands up is a signal to stop.—*Fig.* 5.

A man holding one arm up, is a signal to go slowly.—*Fig.* 6.

A man holding his right arm in a horizontal position, is a signal to go on.—*Fig.* 7.

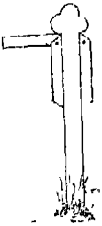
The semaphore signal is invariably made from the left-hand side of the post, as seen by the approaching engine-driver.

Intermediate Station or Junction.—On a Train or Engine stopping at or passing an intermediate station or junction, a stop signal must be exhibited for five minutes; after which a caution signal must be exhibited for five minutes more. On a Train or Engine passing a level crossing or siding where a signal-man is stationed, the stop signal must be exhibited for two minutes; after which a caution signal must be shown for eight minutes more.

DISTANCE SIGNALS.—At some of the stations, and at other places on the line, distance signals are placed in advance of such stations or other places. These must be placed to "Caution" when the train has to stop at the station, place, or siding, and so soon as the train has come within them raised to "Danger," at which they must remain until the train leaves the station, siding, or other place, when they will be lowered to caution and remain there three minutes. These signals are intended to warn the

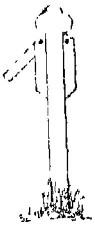
SIGNALS.

Nº 1



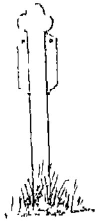
Stop

Nº 2



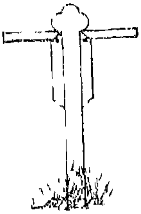
Go slowly

Nº 3



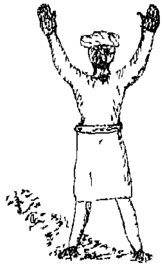
Go on

Nº 4



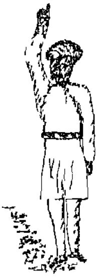
Both Lines
obstructed

Nº 5



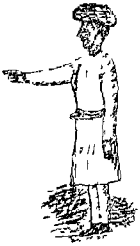
A regular signal
to Stop

Nº 6



To Go Slowly

Nº 7



To Go on

enginemen and guards that similar signals of danger are exhibited at such stations or other places. They are, however, merely auxiliary to the fixed signal in connection with which they work.

Junction Signals.—Many of the junctions are provided with two semaphore signal posts; and the signals for each line are shown on the signal post appropriated to it: the post for the main line being always on that side of the branch signal post which the main line takes, whether it may be to the right hand or the left.

At all the junctions the semaphore arms for day, and the lights for night signals, always stand at danger; and no Engine must pass without the arm is lowered to caution, or the green light is shown.

Enginemen will give the following signals on approaching a junction:—If the train is intended to pass along the main line, the enginemen must give one long, distinct whistle; but if the train is intended to pass along the branch, the engineman must give three distinct whistles; in accordance with which the pointsman will turn the train upon the main line or branch, as indicated by the respective signals.

Whenever two trains are approaching a junction at the same time, both are to be stopped; the pointsman will then start that train which ought to taken the precedence; and passenger trains are always to precede goods, cattle, or mineral trains. And when there are two passenger trains at a junction at the same time, the one which is first due must be allowed to proceed first.

Train Signals.—Every engine belonging to this Company must carry by night a white light on the buffer plank, for passenger,.and a green light for all other trains.

Every train, after sunset, must carry two red side lights and one red tail light.

A red board or flag by day, or an extra red tail light by night, attached to the back of an engine or train, denotes that an extra train is to follow.

Level Crossings, &c., &c.—All level crossing gates of public highways must be provided with lamps, showing red up and down the line when the gates are closed across the line.

Rules for Engine Drivers.—Each engineman, before starting, must obtain a printed form, provided for the purpose, upon which he must enter the quantities of all the coke, oil, tallow, &c., received by him during the day, as also the number of miles run, under their respective heads; and the return must be given in to his foreman every evening, or before ten o'clock the next morning, under a penalty of one shilling for each neglect thereof.

Every engineman must have with him the following tools, &c., and he will be held responsible for having them always in good condition:—

1 Complete set of screw keys.
1 Large and small monkey wrench.
3 Cold chisels.
1 Hand hammer.
1 Crowbar.
1 Fire bucket.
Gauge, and head and tail signal lamps.
Quantity of flax and twine.
1 Large and 2 small oil cans.
1 Screw jack.
2 Coupling chains, with hooks.
1 Tallow can.
1 Red signal flag.
1 Time book.
Plugs for tubes, with a plug rod and quarter hammer.
6 Detonating signals.

Enginemen on bringing up their trains are to pay particular attention to the gradients, state of the weather, and condition of the rails, as also to the length and weight of the train; and these circumstances must have due weight in judging when to shut off the steam, and when to apply the breaks.

Method of working a single line between the stations A and B, with an intermediate Station, S.—A Train staff or train ticket is to be carried with each train, to and fro, without which no engine is to be allowed to start.

Two train staffs will be employed, viz., one between A and S, *red*; one between S and B, *blue*.

No engine, or train is to be permitted to leave either A, S or B, unless the Staff for the portion of the line over which it is to travel is then at the Station. If no second engine or train is intended to follow, the staff is be given to the Guard or person in charge.

If another engine or train is intended to follow before the staff can be returned, a train Ticket, stating "Staff following," will be given to the person in charge of the leading Train, the staff itself being given to the person in charge of the last train, after which no other engine or train can leave the Station, *under any circumstances whatever*, until the return of the Staff.

The Train Tickets are to be kept in a box, fastened by an inside spring; the key to open the box is the train staff, so a Ticket cannot be obtained without the train staff.

The Train Staffs, Ticket boxes, and Tickets are painted or printed in two different colors, red between A and S, and blue between S and B.

The inside springs and the keys in the Staffs being so arranged that the red Staff cannot open the blue box; nor the blue Staff the red box; this is to prevent mistakes at S.

The Ticket Boxes are fixed by two brackets in the Booking Office, the brackets being turned up at the end to receive the Train Staff when at the Station.

The Clerk in Charge, Inspector, or person in charge for the time is the sole person authorised to receive and deliver the Staff.

252. The general charge of the engines of a line is under the *Locomotive Superintendent*, who is assisted by one or more *foremen of locomotives.* The names of these sufficiently explain their business. Every engine has or ought to have its own engine driver, (as well as fireman,) as it is a well known fact that no two engines though turned out of the same workshops and from the same patterns, will work exactly alike. The engine driver's post is one of great responsibility, and requires presence of mind and decision of character as well as a thorough knowledge of his business.

Every train is under the charge of a *Guard*, to whom the engine driver looks for orders as to stopping or starting, and who when the train is at a station is under the orders of the station master. The guard signals to the engine driver by a whistle, and a means of communication between the two is provided to be used when the train is in motion and the whistle cannot be heard. There ought also to be a proper means of communication between the passengers and guard, by which his attention can be called to any particular carriage if necessary, but though it has often been urged, on very few lines has it been carried out.

Every station has a *Station Master*, assisted by a staff of porters, &c., who attend to the local traffic whether of passengers or goods.

Besides these officials there are also at the terminal stations a *Good's Superintendent*, a *Superintendent of Workshops* with his staff, and others whom it is not necessary here to mention.

For the Engineering duties of a line when made and opened, there is a *Resident Engineer*, with one or more assistants or District Engineers, and a staff of *Inspectors of Permanent Way* or *Foremen Platelayers*, whose duty it is to inspect their section of the line daily, and see that it is in proper order; they are provided with *gauge rods* to see that the gauge is accurately preserved.

CHAPTER XLV.

HORSE RAILWAYS.

253. ALLUSION has been already made in the first chapter of this section to light Branch Railways, now under construction in India,—which are intended to be more cheaply constructed than the main lines, and to be worked at low speeds. The same principles may be carried yet further; and in districts where cheapness of construction and working is of more consequence than speed, horse or cattle power may be advantageously substituted for the locomotive.

The saving in such a system will consist chiefly in the lighter kind of permanent way and rolling stock that may be employed on such a line, though more saving may also be effected in the sharper curves and steeper grades that are allowable for low speeds, and in the less expensive character of the stations. But it will be better as a rule in constructing all such lines to contemplate the probability of locomotives being hereafter substituted as the traffic develops, and it will generally be bad economy to estimate any saving on an ordinary railway in the roadway itself up to formation surface.

The whole question is so obviously one of expense, both as regards first cost, traffic, and working expenses, that it will be sufficient to give the best data available, and leave the Engineer to apply the same principles to any particular case with which he may have to deal.

254. The following estimate, drawn out by Sir William Denison, has special reference to the Madras Presidency, but will be found in most points generally applicable:—

Horse Railway.—The cost of the earthwork, and of the bridges, and culverts, would be rather less on the railroad than on the macadamized road; for while it is not intended to modify the gradients in any way, or to add to the cuttings and embankments, except on very special occasions, the width of the road may be less. I do not, however, propose to make any deductions on this account, but shall assume the cost of the earthwork and *bridges and ballasting, at the same sum as for the macadamized* road, viz., £750 per mile; (*see* ante p. 183), setting the metalling against the ballast of the Railway. The cost therefore, of a railroad will be found by adding to the cost of the macadamized road, that of the purchase of rails, chairs, and sleepers, and that of the labor of fixing them.

The weight of the rail used at first on the Manchester and Liverpool line was 35 lbs. to the yard, and it seems to me that, for horse traction, a rail 28 lbs. to the yard would be amply strong enough; and as 2,000 yards, or an addition of 240 yards to the mile, will be sufficient to cover all sidings, &c., 2 × 28 × 2,000 = 112,000 lbs., or 50 tons per mile, will be the weight of the rails. These can be delivered at Madras at £8 10*s.* per ton, and an additional 30*s.* per ton, making a total of £10 per ton, will cover the charge for conveyance, so that £500 will be the cost per mile of the rails delivered upon the road. Timber sleepers have been found to decay rapidly in this climate; I should therefore be inclined to recommend the employment of stone blocks as supports for the rail; in many parts of this Presidency, where the gneiss crops out on the surface, the stone block would be far cheaper in first cost, and far more durable than any other description of sleeper; but, as these may not be attainable generally, I propose to allow for the use of the iron pot sleepers, which have been employed on the Railway. For the horse traction line these may be made lighter than for the locomotive line, but I propose to allow for the same weight and price, that is £1 per pair of sleepers with the connecting tie-rod. I shall allow, however, for a bearing of five, instead of four feet; the cost, under these conditions, of chairs and sleepers will be £1,200 per mile.

The cost of laying the railway may be put as on the Locomotive line, at 4½*d.* per yard run, the cost for 2,000 yards would therefore be £37 10*s.*

In order to make the action of this railroad perfect, it should be provided with a line of Telegraph; and the cost of this, judging from the amount expended upon that on the Madras line of railroad, will be £90 per mile.

The whole cost of this railroad for animal power per mile will then be as follows :—

	£	s	d
Earthwork, including ballast or metal,	330	10	0
Bridges, culverts, &c., ...	302	10	0
Rails, ...	500	0	0
Chairs and sleepers, ...	1,200	0	0
Fixing rails, ...	37	10	0
Telegraph, ...	90	0	0
Stables and rest-houses, . .	50	0	0
Sundries, ...	40	0	0
Superintendence, &c, ...	76	0	0
	£2,627	0	0*

An allowance must be made for the wear and tear of rails and sleepers. The actual wear of the road itself will be very much less of course than that of the macadamized road, for the iron rail takes the action of the wheel; if, then, the rails and sleepers are renewed in twenty years, one-twentieth of the whole cost may be provided as an annual charge; and as this cost is £1,700, one-twentieth of that sum will be £85. One-half of the ordinary sum of £30 will be sufficient to cover the cost of other repairs; so that 85 + 15 = £100 will cover the cost of the maintenance of the Railway for animal power.

Cost of Haulage.—I have now, however, to form an estimate of the cost of conveying the same quantity of goods, and the same number of passengers, along a *Railway* by means of *animal power*.

The number of first-class passengers has been put at 3,220, or roughly 10 per day, or 5 each way. To convey these one first-class carriage would be required, which would travel at the rate of 10 miles per hour It would be drawn by two horses, and would be capable of accommodating 16 passengers. The distance of 41·25 miles would be divided into five stages, each pair of horses going a stage out and a stage back, or about 16 miles per day; a spare carriage would be required and a spare pair of horses

The capital expended would be—

	£		£	s	d
3 Carriages, ...	at 250	=	750	0	0
12 Horses, ...	at 45	=	540	0	0
10 Sets harness, ...	at 10	=	100	0	0
	Total, .		£1,390	0	0

152,000 second-class passengers divided by 365, will give 416 as the daily number conveyed both ways. It will, however, be necessary to reckon upon some extra pressure occasionally; and carriage accommodation must be provided for, say, 240 each way, or 480 altogether Each carriage will contain 30 passengers, and will be drawn by two horses at the rate of about 6 miles per hour; travelling the same distance as the horses drawing the first-class carriages.

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* This estimate agrees closely with Captain Yule's careful estimate, in his project for a railway in Rohilkund, of a Cattle Draught line, at Rs 26,500 per mile, but this includes Rs. 2,532 for plant and wagons, which are chargeable to draught rather than construction It is considerably highe than Mr. Wilson's estimate for a light Railway to be worked by locomotives —[ED.]

The total number of carriages and horses required for the actual work will, therefore, be 16 carriages and 80 horses, but it may be as well to estimate for 20 carriages and 100 horses

The capital expended, then, upon rolling stock and animal power will be—

	£	£	s	d
20 Carriages, ...	at 250 =	5,000	0	0
100 Horses, ...	at 40 =	4,000	0	0
16 Sets harness, ...	at 10 =	160	0	0
	Total, ...	£9,160	0	0

32,000 tons of goods may be put at 100 tons per day, or 50 tons each way

Three tons may be allowed for each truck, and 34, therefore, would be required; each would be drawn by 3 bullocks, 6 extra trucks might be allowed to meet casualties; and a few extra bullocks should be purchased As the daily journey of a bullock may be put at ten miles, the distance of 41·25 would be divided into four stages; so that 12 bullocks would be required for each truck, 40 × 12 = 480, would be in daily use, or say 500 to cover contingencies.

The trucks ought not to cost more than £100 each, and the bullocks £15 the pair

The capital, therefore expended upon the rolling stock and animal power for the goods traffic will be—

	£	s.	d.	£	s.	d.
40 Carriages, at	100	0	0 =	4,000	0	0
500 Bullocks, at	7	10	0 =	3,250	0	0
			Total, ...	£7,250	0	0

The total amount of dead and live stock required for the conveyance of passengers and goods along a Railway worked by animal power would be as follows:—

	£	s.	d.
First-class passengers, ...	1,390	0	0
Second-class do., ...	9,160	0	0
Goods, ...	7,250	0	0
Total, ...	£17,800	0	0

Say £18,000.

The annual charge may be estimated as follows:—

	£		£	s.	d.
Interest upon £18,000, at 5 per cent.,		=	900	0	0
Wear and tear of carriages and repairs, 15 per cent., on	9,750	=	1,462	10	0
Cost of re-placing horses and bullocks, 15 per cent., on	7,790	=	1,168	10	0
Repairs and re-placing harness, 20 per cent., on	260	=	52	0	0
Keep of 112 horses, at £24 each,		=	2,688	0	0
Keep of 500 bullocks, at £8 each,		=	4,000	0	0
Hire of 20 coachmen, at £50 each,		=	1,000	0	0
Hire of 166 bullock drivers, at £10 each,		=	1,660	0	0
Repairs of stables, at 5 per cent. on	2,000	=	100	0	0
Telegraph, &c., charges as on locomotive line,		=	11	9	0
General charges, including clerks, &c.,		=	442	11	0
		Total ...	£13,485	0	0

This sum divided by the total distance 41·25 miles, will give the charge per mile for traction, £302 12*s.* 10*d.*

255. The following Notes are extracted from a Report drawn up in 1855, by Captain Yule, R.E., on a projected light Railway in Rohilcund:—

We have in this country no cattle-draft railway for general traffic, though we have at Roorkee, and also, I believe, at the great Godavery works, light railways in operation for special constructive purposes. There is, or was also, the Redhill railway at Madras, established for the purpose of bringing road metal into the city; but I find no account of it accessible to me at present.

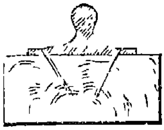
Such railways English books now utterly ignore. The idea of railways for general traffic, had scarcely begun to be taken in by the public mind in England, when the superadded invention of the locomotive engine took entire possession of the field. Yet horse railways are still worked, I believe successfully, in Germany; and in America they were, at the commencement of the railway system, numerous. The American edition of "Woods' Railways" contains an account of many such.

If they can be worked with profit at all, the advantages they hold out in the power of working with so much lighter material and less costly establishment in this country, where so much costly material and costly management has to be imported for the working of a locomotive system, must strongly recommend them where there is a considerable, but not unlimited traffic to be expected.

In the comparison between animal and locomotive power for the project, gradients will not enter much into question, excepting at some of the bridges, and the earth-work will form so small a proportion, probably, of cost, that little can be saved on it by preferring the former. Steeper gradients may be admitted, if necessary, on the cattle railway, not because cattle are at all less sensible to the tendencies of gravitation than locomotive engines, but because the remedy of additional power can be more cheaply applied, where wanted.

In such a railway, as we now propose, there would be no object that I can see in keeping the gauge of the East Indian Railway. We make the railway for cattle draft, and adapt it to that. Neither the way nor the establishment will be prepared for locomotives, and it may be as well to make it impossible for the locomotives, at least of the East Indian Railway, to come upon the line. We *must* have a break of line, where we meet the East Indian Railway, and it may as well be a break of gauge.

The narrower gauge enables us to make some reduction in the cost of works and way, and a larger reduction in the cost of wagons. I therefore propose that the gauge should not exceed 4 feet 6 inches. The rail intended to be used is the flat-soled American pattern, used on the Croydon, the Birmingham and Gloucester, and many German lines, giving it a weight of 30 lbs. to the yard.



Estimate for one mile of Cattle-draft Railway for a main line in Rohilkund.

	RS.
Earthwork, averaging 4 feet high, and 10 feet wide at top, slopes 3 to 1, cubic feet 4,64,640, at Rs. 2,	929
Sand ballast, 1 foot thick, cubic feet 36,960, at Rs. 1 per 100,	370
Brick, or natural ballast, ½ foot thick, cubic feet 18,480, at at Rs. 6,	1,109
Longitudinal timbers, 8 inches × 4 inches, 10,560 running feet, or cubic feet 2,347, at Rs. 1,	2,347
Cross-ties, 883 in number, or cubic feet 978, at Rs. 1,	978
Spikes, 4,000 lbs., at 3 annas,	750
Laying way, per yard, Rs. 1,	1,760
Rails, 30 lbs. to the yard, 48 tons, at Rs. 160,	7,680
	15,923

Add :—

	Rs.
For sidings $\frac{1}{10}$th, ...	1,592
For culverts and small bridges brick-work, 6,000 cubic feet, at Rs. 16, ...	960
For large bridges, ...	3,893
For station buildings, ...	800
Fencing and gates, ...	800
Plant and wagons, ...	2,532
Total Rupees per mile, ..	26,500

We have in this country an establishment, somewhat analogous to that of a good railway, in the Government Bullock Train. From data, lately furnished to me by the Superintendent it appears that the cost of transport by the Train, averages little under 1 anna per ton per mile. And as a horse can draw at least eight times as much gross weight on a level railway as it can on a level turnpike road, we might divide one anna by eight, and call that the amount of working expenses per ton per mile.

It is however to be remembered that the Bullock Train establishment is in happy ignorance of the expenses of road maintenance, which are charged to another department. Neither is it self-dependent in the matter of establishment, which for the most part is identical with that of the Post Office. A part is charged to the Train, but of course this is less than if the transport system stood alone. And, not to go into other sources of enhanced expense, the cost of "rolling stock" adapted to a railway will be in a heavier ratio than in the case of the Bullock Train.

The great difficulty that I foresee on a cattle railway will be that of keeping our rolling stock within reasonable limits. Draft horses for a purpose such as ours, can scarcely be said to exist in India, and we must therefore look to oxen for our draft. Oxen move slowly, and we must consequently keep up a larger establishment of wagons. Such speed as we expect to gain over that of the present country transport will be rather by the advantage of relays and constant movement, than by any great acceleration of rate whilst in motion.

Let each wagon be supposed to carry two tons. For 30,000 tons to be moved at once, we should require ... 15,000 wagons.

These wagons travelling day and night, we may suppose to accomplish the journey of 120 miles in 3 days, and to return in the same, halting on Sundays. We may therefore count on the same wagons starting from Bareilly once a week, or making 43 trips in 300 days. We require, then, to keep up this traffic, .. 350 wagons.

Or allowing 150 spare, as our establishment, ... 500 wagons.

The cost of these is supposed to be included in our mileage estimate of construction. But the carts may be expected to require renewal at least every five years. Supposing the cost of a wagon to be 500 Rs. then $\frac{500}{5} \times 500$,.. .. .. Rs. 50,000 for cart repairs (*a*)

Next for Cattle—

The Bullock Train establishment obtains them at a contract rate of 12 rupees per pair per month. But I fear that our large concentrated demand would scarcely obtain cattle at so low a rate. Let us say half a rupee per diem for the pair.

Allowing two wagons, or four tons nett to a pair of bullocks (and 12 miles a stage, the practice of the Bullock Train), to carry at once our load of 30,000 tons, would require

$7{,}500 \times \frac{120}{12}$ .. .. (Rs. 75,000)—pairs of bullocks.

Or, divided over 300 days, ... (Rs. 250)—pairs.

We may find, however, that we have to pay such a rate as will cover the hire or keep of the cattle for the whole year, or 365 days, instead of 300; hence $250 \times \frac{1}{2}$ R. $\times 365$, Rs. 45,625 for the cost of cattle (*b*)

Establishment it is more difficult to estimate. But as one reason in favor of a cattle, rather than a steam railway, is the expectation of preserving a moderate scale of establishment, probably something like this would suffice,

Superintendence of works and traffic,	Rs.	1,500	
Two terminal stations, ...	,,	700	
Ten minor stations, ...	,,	1,500	
Monthly, ...	Rs.	3,700	
Or Annually, ...	Rs.	44,400	for establishment (*c*)

Maintenance of way.—With the slow movement of a cattle line this ought not to be heavy, say Rs. 150 per mile, ... $150 \times 120 =$ Rs. 18,000 for maintenance (*d*)

The account will stand thus:—

	RS.
Repairs of rolling stock, &c.,	50,000
Hire of cattle,	45,625
Establishment,	44,400
Maintenance of way,	18,000
Total	1,58,025
Or per mile,	1,317

The cost of carrying 1 ton a mile will be

$$\frac{\text{Rs. } 1,58,025}{30,000 \times 120} \quad \ldots\ldots\ldots\ldots \quad 0{\cdot}702 \textit{ Annas.}$$

The present average cost of transport by country carts is 1·8 annas per ton mile.

The gross receipts on 30,000 tons, would be per mile:—

	RS.
At 1½ anna,	2,813
Or @ 1¼ anna,	2,344
And the expenses being, as above,	1,317
The nett revenue, per mile, will be,	1,496
Equal to 5·64 per cent. on construction, or	1,027 equal 3·9 per cent.

SECTION X.—IRRIGATION WORKS.

256. IRRIGATION is either Natural or Artificial. The former depends upon Rain, upon Wells, and upon the flooding of Rivers. The latter comprises two important classes of Works—Canals and Tanks—which will be treated of in their proper order.

With Rain Irrigation the Engineer has nothing to do except under the head of Drainage of Lands; a separate branch of Engineering which will only be treated of incidentally under this Section.

CHAPTER XLVI.

WELL IRRIGATION.

257. With Well Irrigation the Engineer's chief business is to devise machinery for raising the water, which more properly belongs to the subject of Mechanical Engineering.

It may be useful however to show the cost of raising water by the various methods generally used in India,—if only to show the utility of introducing Canal or Tank Irrigation even in districts already irrigated by wells. Some idea may be formed of this when it is considered that the Ganges canal alone is calculated to perform the work of 300,000 men and 1,200,000 bullocks, besides increasing the produce of *well* irrigated crops by 50 per cent.

The three modes in general use for raising water from wells in India are the *Paecottah* for Bengal (and (I believe) Southern India, when tanks do not exist), the *Môt* or *Churus* for the N. W. Provinces, Rajpootana, &c., and the *Persian Wheel* for the Punjab.

The *Paecottah* or *Latha*, is a lever with a bucket at one end attached by a rope, and a counterpoise at the other end. It is worked by two men, who will work at it from 6 to 8 hours daily, and, it is said,* they will in 6 hours raise 2500 cubic feet of water from a depth of 20 feet. Another calculation† however gives 1357 lbs. of water as drawn from a depth of 36 feet in half an hour, equivalent to 260 cubic feet in 6 hours, and this result, making allowance for the difference of lift, differs so widely from the first, that neither can be taken as a guide. When the depth is moderate (according to the same authority) three men with two lathas will water from one-third to two-thirds of an acre daily.

The walking beam is another form of the paccottah, by which one man, it is said,‡ can raise 400 cubic feet in a working day of 8 hours from a depth of 11 feet, which agrees better with the second of the two calculations given above.

The *Môt* or *Churus* used in the N. W. Provinces, and elsewhere, consists of a leathern bag made from a whole ox-hide, which, when filled, is raised from the well by 2 bullocks walking down a slope, and emptied by an attendant on arrival at the top. Sometimes it is fitted with a leathern pipe at the bottom of the bag, which, by means of a string, can be worked by the bullock driver from the end of the slope, so as to empty the bag and dispense with the services of the attendant. Sometimes also by means of a drum two môts are worked, one being raised while the other is lowered.

" Three men and two oxen work a môt from morning until evening, with a refreshment only of about ¾ths of an hour. In a well 33 feet from the surface to the water, a môt in half an hour drew 7210 lbs; but such superiority over the lathas is not admitted by the natives, who contend that three lathas wrought by four men are equal to a môt wrought by three men and two oxen. This however, I have no doubt, is a mistake, unless when the water is very near the surface."§

‖ " From personal measurement we deduce that a leather bag as used in the North-West Provinces, contains 4·5 (four and a half) cubic feet, and that two pair of bullocks, relieving each other in the manner above described, will raise this bag full of water to the surface of the ground forty times in an hour. Supposing the bullocks work ten hours a day, and taking ninety days as the working season, we have the following result:—
4·5 × 40 × 10 × 90 = 162,000 cubic feet. One acre = 43,560 su-

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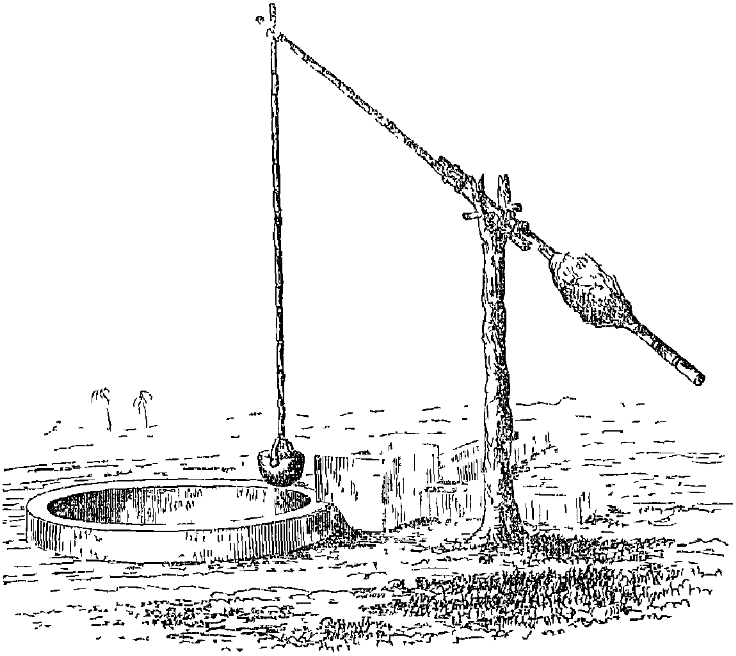
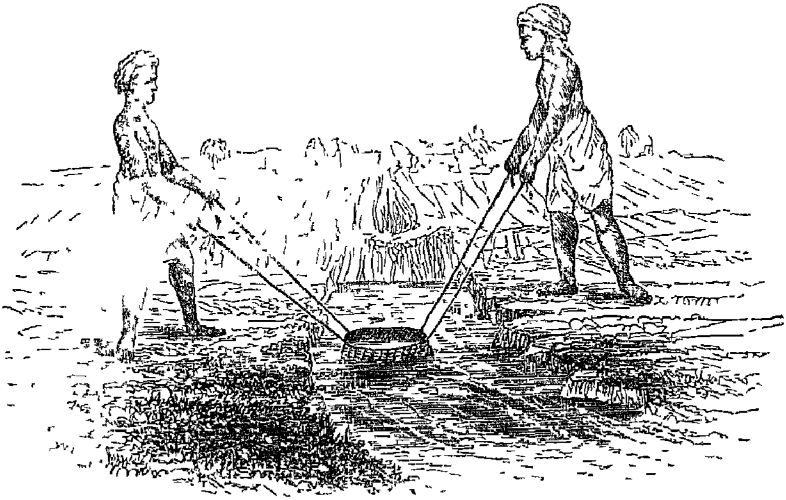
* Madras Engineer Papers, Vol II † Gleanings in Science, Vol II. ‡ Gleanings in Science Vol I
§ Gleanings of Science. ‖ Calcutta Engineer's Journal.



THE PAECOTTAH



BALING.

perficial feet. $\frac{162000}{43560} = 3{\cdot}72$ acres, covered 1 foot deep with water, as the result of the labor of two pairs of bullocks and three men, working ten hours a day for ninety days. From the above description of the well system of Irrigation, it will be seen that it is very expensive, and can only be of very restricted application.

"Beside the objection of expense in working, this system is quite impracticable in large tracts of the Doab, as the sandy nature of the sub-soil entails the necessity of masonry wells, and it is quite plain that such a well, costing at least Rs. 500 to even every 20 acres, is entirely out of the question. The ordinary well is simply a round hole, lined, for a few feet of its height from the bottom with a wooden, or plaited brush-wood casing."

258. The *following Notes on this subject*, from Colonel Dickens's Report on the Soane Canals, will also be found useful:—

The irrigation of the spring crop is for the most part effected by drawing water from wells by means of bullocks and the leather bag called a *moth*. In some places, where the water is near the surface, the weighted level *(lāt)* is used, but it is a more expensive mode of raising water than by the bullocks and *moth*, except where the depth of the wells is very small.

The wells are not deep, reaching generally from 18 to 28 feet below the surface :* on the average perhaps 22 feet. But the supply of water is in most parts of the district scanty, and little more than a foot remains in the wells while the *moth* is in use.

To irrigate the crop the water is run through the fields in channels, whence it is sprinkled over the crop with wooden scoops. This mode of irrigation is very inferior to that practised in other parts of India (and for opium in Shahabad) of allowing the the water to submerge the whole field, plot by plot.

With wells of the average depth the irrigation requires two pairs of bullocks (to work and rest by turns) and two men at the well, besides a woman or boy in the field to form the channels and sprinkle the water. On an average one *moth* will water about $\frac{3}{8}$ths of a beegah ($\frac{2}{9}$ths of an acre†) in a day. A laborer who has received an advance of money from his employer gets $2\frac{1}{2}$ or 3 seers (5 or 6 lbs) of one of the cheapest kinds of grain as his daily wages, value about 3 pice of 20 or 21 *gundas* (or fours) to the rupee (that is 80 to 84 to the rupee, 40 to 42 pice to a shilling). A laborer not in debt is allowed 4 seers of grain, value about 4 of the pice current in the district, or $\frac{3}{4}$ths of an anna of the Company's coinage ($1\frac{1}{8}$ penny) as his day's wages. I was not able to form a satisfactory direct estimate of the cost of keeping up the bullocks and their gear with the *moth*, but I found the established rate of hire for the two pairs of bullocks with gear and moth is 4 annas (6 pence) a day. The cost to the proprietors would, I suppose, be something less. I therefore set down the cost of one day's irrigation from wells.

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* This refers to the Shahabad and other districts in Behar. In the Punjab the distance to the surface of the water from the ground is often 40 or 50 feet. The length of time then consumed in raising the Môt makes it inferior to the Persian Wheel, hereafter described, which gives a continuous stream.—[ED].

† The beegah of 3,025 square yards is used in Shahabad.

	RS.	A.	P.	£	s.	d
2 men	0	1	6	0	0	2¼
1 woman or boy, omitted, being also required for canal irrigation, ...	0	0	0	0	0	0
Bullocks and *moth*, ...	0	3	6	0	0	5¼
One day, or to water ⅗ths of a beegah, ⅜ths acre,	0	5	0	0	0	7½

To water a beegah once, therefore, costs, .. Rs. 0 8 4
And acre, ... £ 0 1 8

The greater part of the spring crop is watered only once or twice in the season, but some of it three times, particularly wheat. Wheat in some few places is watered four times. Where the irrigation was industriously applied, I generally found the rule to be to water barley twice and wheat three times. The excuse for not irrigating more in places where the above was not acted up to, was more frequently want of *time* than want of *water*. I am inclined to think the real cause is often indolence rather than scarcity of labor. But for either case the supply of canal irrigation affords a remedy, as it saves both laborers and trouble.

Excepting in the rich land near the Ganges and a few other favored spots, the unirrigated crops of wheat and barley are very scanty, and are said to produce only from 2 to 6 maunds of grain per beegah (256 to 640 lbs. per acre), and those irrigated once or twice yield only from 4 to 8 maunds (512 to 1,024 lbs. per acre). Irrigated three times, the crop is said to yield from 7 to 10 maunds (896 to 1,280 lbs. per acre); but the people told me if they could irrigate 4 times, using abundance of water, they would get from 10 to 15 maunds of grain per beegah (1,280 to 1,920 lbs. per acre).

Colonel Cautley states the produce in the Seharunpoor and Bolundshuhur districts to be about 8½ maunds per beegah for unirrigated, and 13 maunds for irrigated, land (1,089 and 1,702 lbs. per acre). There is certainly a very much greater difference than this in most parts of Shahabad; and allowing for some exaggeration in the native account above given, I think the supply and use of abundance of water to irrigate the crops would double the produce of the greater part of the district.

Watering three times in the imperfect way above described, costs as above shown about Rs. 1-9-0 per beegah (5 shillings an acre) for the season*, and it is evident that the money is well laid out. Doubling the rate of water rent levied in the North-Western Provinces (that is charging Rs. 1-4-0 instead of Rs. 0-10-0 per beegah), 4 shillings instead of 2 per acre, we should be able to supply the cultivators with irrigation 25 per cent. cheaper than they get it now, and, in addition, give them all the advantages of 4 thorough drenchings for their crops instead of 3 sprinklings. They will besides have the canal supply of water all the rest of the year without any further payment, and will be able to turn it to more profitable account in raising more valuable crops than the wheat and barley, which alone I have calculated upon.

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* Lieut.-Col. Baird Smith (page 381, Vol. I., Italian Irrigation) makes it (omitting interest of capital) £1-11-2¾. He has, however, calculated the hire of the men and beasts for the whole year, while my calculation extends only to the period of irrigating the spring crops. Taking the irrigating season at 4 months or ⅓rd of the year, the rate comes to £0-10-4¾. The difference between this and my estimate may be owing to the greater depth of wells and the more liberal scale of irrigation. But the wages and cost of bullocks differ greatly from those in Shahabad.

I found the water bags used in Shahabad hold on an average about 2¾ cubic feet of water. They were worked for short periods at the rate of about 25 per hour, but that was not kept up throughout the day, and the total number raised daily was said not to exceed 150. To be sure of making a liberal calculation I shall, however, take it at 300. This therefore I take as the bulk of water required for ⅗ths of a beegah (⅜ths of an acre) for one watering. For a whole beegah this gives 500 bags (800 per acre) for one watering, and 2,000 (3,200 per acre) for four waterings, or a full season's irrigation. But this is for the imperfect kind of irrigation practised in Shahabad. To irrigate thoroughly I shall suppose double the quantity of water necessary, that is, 4,000 bags or 11,000 cubic feet per beegah (17,600 cubic feet per acre).

The irrigating season in Shahabad commences about the beginning of November and terminates at the end of February. It lasts, therefore, about 120 days. Now one cubic foot of water per second for 120 days is 10,368,000 cubic feet, which will water 942 beegahs or 588 acres. But this is the supply to be delivered from the canal, and it is necessary to add to it the quantity required to make up for the wastage in passing down the channel, in order to determine the discharge required at the canal head.

259. The following detailed calculations of the performance and cost of various irrigating machines are extracted from *Professional Papers*, Vol. I.

The heights assumed for raising the water in each case are those for which it is believed the several machines could be most generally and usefully employed.

The value of the modulus and the useful effect in each case are assumed after due consideration of the structure of each machine and the amount of spillage or waste.

1. *The Paecottah.*—(One man employed).

Water raised 16 feet. Content of bucket = ·45 cubic feet.

Number of discharges per minute = 3. Discharge per hour = 81 cubic feet.

If we take the useful effect or discharge at 90 per cent., we get—

Actual discharge per hour = 72·9 cubic feet = 455·4 gallons.

2. *Baling.*—(Two men employed).

Water raised 5 feet. Deliveries in each minute = 20.

One delivery = ⅓ cubic foot. Delivery per hour = 400 cubic feet.

If useful effect = 75 per cent., then—

Actual discharge per hour = 300 cubic feet = 1890 gallons.

3. *The Single Môt.*—(One man and two bullocks employed).

Water raised 40 feet. Speed of bullocks = 2 miles an hour.

Space gone over by the bullocks at one lift = 80 feet. Content of bag = 3 cubic feet.

Time required for bullocks in turning = ·4 minute.

Number of lifts per minute = 1·18.

Discharge per hour = 213·6 cubic feet. Useful effect = 70 per cent.

Actual discharge per hour = 149·5 = 924 gallons.

Taking the modulus = ·9 and the weight of the rope and bag = 42 pounds, the required traction which the bullocks have to overcome is = 255 pounds.

4. *The Double Mot*—(One man and two bullocks employed)

Water raised 40 feet. Speed of bullocks = 2 miles an hour.

Diameter of barrel = 3 feet. Diameter of bullock walk = 16 feet.

Number of turns of bullock per minute = 3·4.

Total time for raising the bag = 1·4 minute Content of bag = 3 cubic feet

Discharge per hour by 2 bags = 252 cubic feet. Useful effect = 65 per cent

Actual discharge per hour = 165·8 cubic feet = 1045 gallons.

Ratio of power and weight = 3 . 16. Total weight to be raised = 460 pounds.

Taking the modulus = ·7, we get—Work applied = 657 pounds.

Required traction — 124 pounds.

5. *The Single Persian Wheel*—(One man and two bullocks employed)

Water raised 40 feet

Diameter of driving wheel = 4 feet. Diameter of bucket wheel = 4 feet

At each turn of the bullocks, 6 buckets are emptied, and assuming the content of each bucket = $\frac{1}{8}$ cubic foot, we have—Discharge at each turn = $\frac{3}{4}$ cubic foot.

Length of bullock walk = 62·8 feet, and speed of bullocks = 2 miles an hour

Number of turns per minute = 2·8. Discharge per hour = 126 cubic feet.

Useful effect = 55 per cent.

Actual discharge per hour = 69·3 cubic feet = 429 gallons.

Buckets are 2 feet apart. Number of buckets required = 40.

Weight of buckets = 80 pounds.

20 buckets being always full, the weight of the water they contain is = 156 pounds. Weight of rope = 22 pounds.

Total weight to be raised = 258 pounds. Ratio of power and weight = 1 . 5.

Modulus = 0·6 Work applied = 130 pounds.

Required traction = 86 pounds.

6. *The Double Persian Wheel*—(One man and two bullocks employed).

Water raised 40 feet. Proportion of gearing = 2 . 3.

Diameter of driving wheel = 5 feet, pitch = 3·92 inches, cogs = 48.

Diameter of bucket wheel = 3 feet 4 inches, pitch = 3·92 inches, staves = 32.

At each turn of the bucket wheel 8 buckets are emptied, the 2 wheels empty 24 buckets at each turn of the bullocks.

Content of bucket = $\frac{1}{10}$ cubic foot.

Therefore : Discharge of water at each turn of the bullocks = 2·4 cubic feet.

If the bullocks work on a lever of 12 feet, the length of the bullock walk is = 75 feet, and taking their speed at 2 miles an hour, we get—

Speed of bullocks per minute = 176 feet.

Number of turns per minute = 2·3. Useful effect = 60 per cent.

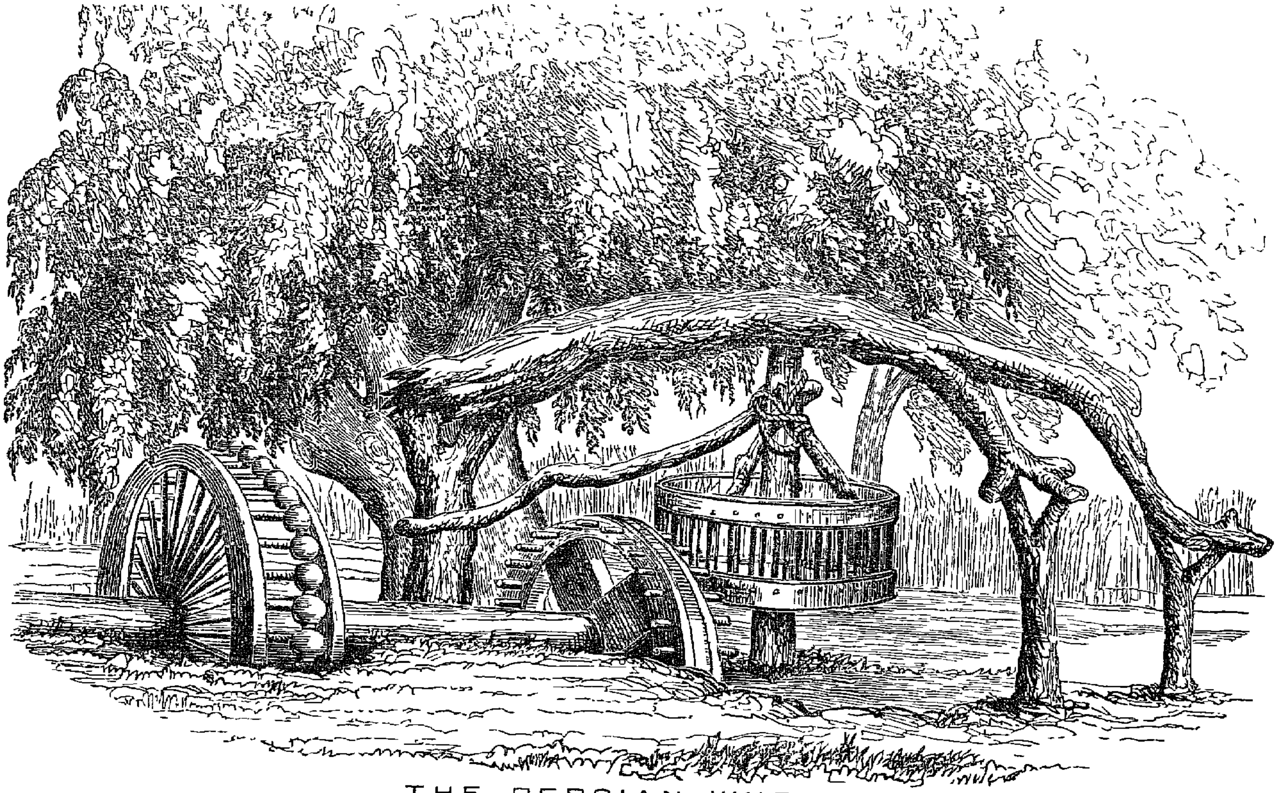
Discharge per hour = 198 cubic feet = 1212 gallons.

The buckets are 1 foot 3 inches apart, and the well being 40 feet deep, the requisite number of buckets for each wheel will be = 60 ; 30 being always full on each wheel, the weight of water on both wheels is = 6 cubic feet = 375 pounds, which is the total weight to be raised, as the weight of the buckets and ropes are not taken into calculation, on account of their balancing each other.

Ratio of power and weight is = 10 : 48.

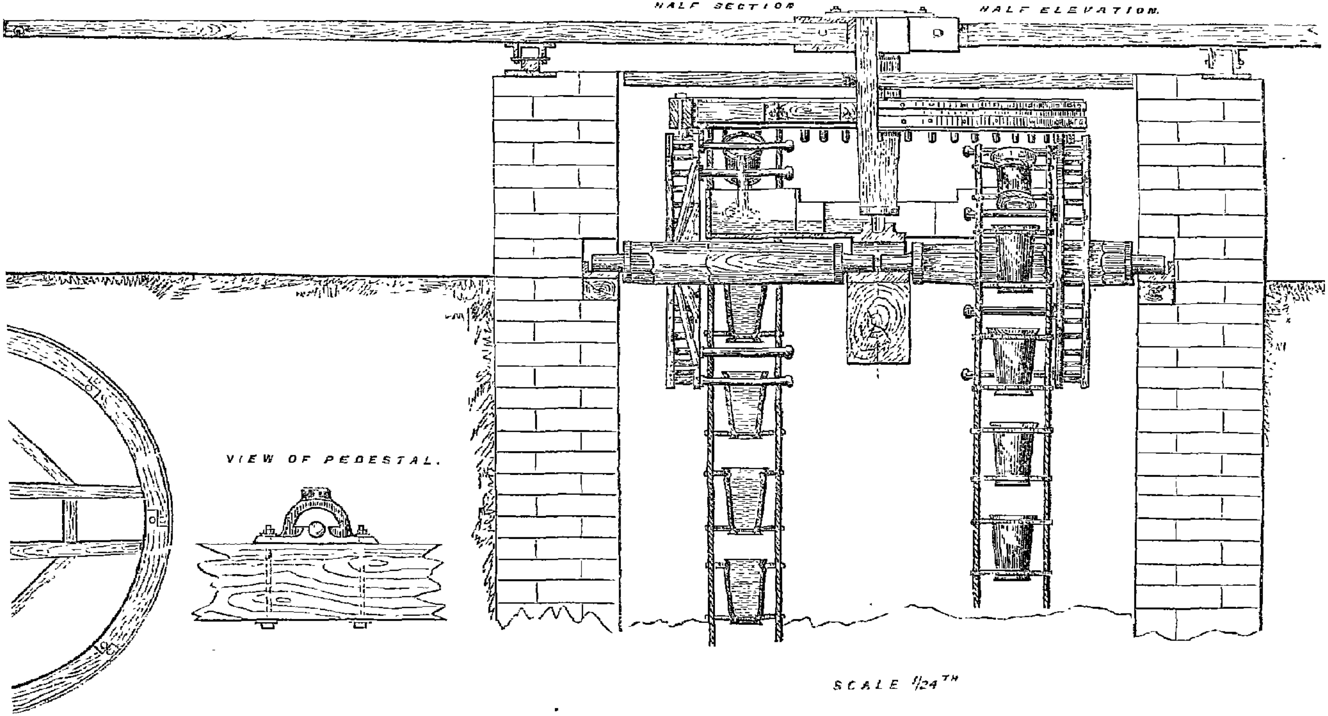
Taking the modulus of the machine at ·5, we get—

Required traction = 156 pounds.



THE PERSIAN WHEEL.

IMPROVED PERSIAN WHEEL.



WOOD ENGRAVING DEPT. ROORKEE

TABLE SHOWING THE COMPARATIVE PERFORMANCE AND COST OF THE ABOVE MACHINES IN RAISING WATER TO THE SAME HEIGHT (40 FEET).

The expense of a laborer is put down at 2 annas, and of a bullock at 4 annas, per diem. Duration of work per diem = 8 hours.

No.	Methods.	Stages.	Useful effect per cent.	Discharge per hour.		Discharge per diem.		Ratio of discharges.	Employs		Daily expense.	Quantity of water raised for one rupee.		Remarks.
				Cubic feet.	Gallons.	Cubic feet.	Gallons.		Men	Bullocks.	Annas.	Cubic feet.	Gallons.	
1	Paecottah, . . .	2·5	90	29·07	181·4	232·5	1451·5	1	2	...	4	930	5806	Discharge increased with decrease of height.
2	Baling, ...	8	75	37·5	*236·2	300	1875	1·29	4	...	8	600	3750	Ditto.
3	Single Môt, . . .	1	70	149·5	924	1196	7392	5·1	1	2	10	1911·8	11827·2	Ditto.
4	Double Môt, . . .	1	65	165·8	1045	1326·4	8360	5·7	1	2	10	2096·6	13478·5	Ditto.
5	Single Persian Wheel,	1	55	69·3	429	554·4	3432	2·4	1	2	10	887	5491	Discharge the same at any height.
6	Double Persian Wheel,	1	60	198	1242	1704	9936	6·8	1	2	10	2534·4	15897·6	Ditto.

* Being $\frac{1}{8}$th of the quantity raised 5 feet high, as computed at p. 303.

The cost and wear of the machines are not taken into consideration. No. 1, or the Paecottah, is taken as unit for the ratio of discharges.

CHAPTER XLVII.

CANAL IRRIGATION—MADRAS AND BENGAL SYSTEMS—INUNDATION CANALS.

260. CANALS are divided into two great classes, those of Irrigation and Navigation. The conditions required to develope one of the former class successfully are—1st, That it should be carried at as high a level as possible, so as to have sufficient fall to irrigate the land for a considerable distance on both sides of it; 2nd, That it should be a running stream so as to be fed by continuous supplies of water from the parent river, to make up for that consumed in irrigating the lands.

The conditions of the latter are, on the contrary, that it should be a still water canal, so that navigation may be equally easy in both directions; and, as no water is consumed except by evaporation or absorption, and at points of transfer from a higher to a lower level, the required quantity of fresh supply is comparatively small, and it is thus most economically constructed at a low level. An irrigation canal, however, may and should be, as a rule, laid out so as to serve for navigation as well; the velocity of the stream being made as gentle as is consistent with its primary uses, so as to afford facilities for boats ascending against it as easily as possible.

261. It is of Irrigating Canals, as forming by far the more important class of the two, at least as regards India, that the ensuing Chapters will principally treat. In England they are unknown, as the rain-fall in that country is so considerable, that the operations of the farmer are principally directed to draining the superfluous moisture from the soil. In Italy, where the climate is hotter and drier, there are many fine canals, of which the late Colonel Baird Smith has given an interesting record to the profession. In India they have been used from time immemorial; and at the present day, Engineers, aided by experience of the past, are proceeding rapidly in the development of these useful works, which so largely contribute to the productive powers of the soil and to the security of the country from famine.

But, it is only of late years that the true principles on which such works should be constructed have been properly studied, or at all understood. The first canals opened out by us in India were those which had been made two or three hundred years ago, in the times of the Mahomedan Emperors, and which had become useless by neglect. The alignment of these was, in all cases, very defective, and as money could only be spared from time to time for their improvement, cheap and temporary expedients were resorted to, to bring them into use, and make them pay as quickly as possible. At first, too, our Engineers, had no experience of such works, nor was there any available quarter from which it could be derived. Much, therefore, was done by "rule of thumb," until the laws of running canals may be said to have gradually worked themselves out. On the Ganges Canal, for the first time there was new ground to work upon, and Sir P. Cautley and his able assistants successfully overcame the difficulties attending that vast project; but much was developed during the actual construction of the work, and, if it had to be done over again, much would, doubtless, be improved. The Baree Doab Canal, in the Punjab, (also an entirely new work,) was commenced some time before the Ganges Canal was opened, and, therefore, has only partially benefited by the improvements suggested since the opening of the latter. Even now, it may be said, that many important questions connected with canal irrigation are undecided, but the experience already gained may be fairly summarized for the use of the young Engineer, to be supplemented by his own hereafter.

262. There may be said to be two distinct systems of canal irrigation carried on at present in the North and South of India, which may be called the Bengal and Madras systems, respectively. The difference between the two arises from the physical peculiarities of each country.

The Madras system has been chiefly confined to the Deltas of the great rivers, such as the Godavery, Kistnah, &c. (and consists in throwing an *Anicut* or dam across the bed of the river to raise the surface level of the water, which is then conducted along canals, whose mouths are above the dam, to the lands requiring it). It is obvious that this system is not applicable to lands at a very high level above the surface of the river, as it would be impossible to raise the water sufficiently to overflow them.

This system is, therefore, confined to alluvial tracts, which have been formed by deposits from rivers in a state of flood.

Nearly all the great rivers of India are thus charged with silt during the rains. In the upper part of their course, where the natural fall of the country is great, and the velocity of the stream is therefore high, this silt is carried forward by the water holding it in suspension, and the action of the stream is generally erosive, and tends to lower the bed; but as the river reaches the plains below, the velocity gradually diminishes, and at last falls below that necessary to carry on the silt, which thus becomes deposited. The effect of this is to raise their beds, and cause them to be constantly shifting their course, and also to raise the ground on both sides of their banks, often for a considerable width, by successive deposits of silt when they overflow their banks. Thus, such rivers will not run in the lowest lines of the valleys, as in ordinary cases, but there will often be a considerable fall from their banks outwards. It is evident this gives great facilities for such irrigation works, as are above described.

But, in the rivers of Northern India, although there is a certain width of land on each side, (known as the *Khadir*,) which has been formed, as above; yet, it is, in general, a very narrow strip. The greater portion consists of a high table land (the *Bangur*), occupying nearly the whole extent of the Doab,* and, in general, rising very abruptly from the *khadir*. It is, therefore, impossible to irrigate this high land by a short cut from the river; the depth of digging would be too great, and the water would never stand at a sufficiently high level to be brought on to the land except by expensive apparatus for raising it. It is necessary to go back to a point high up in the river's course, whence the water can be brought on to the high land by excavation of a moderate depth, and by which sufficient command of level may be obtained to overflow the surface.

The land, in Upper India, bears two crops a year, the *Rubbee* or spring crop, which consists chiefly of cereals, and other productions of temperate climates; and the *Khureef* or autumn crop, which consists of rice, sugar, and other tropical products. As the rivers are at their highest when the *khureef* requires water, so obviously, it is much easier to irrigate this crop, which, however, generally gets a liberal supply from the falling rain. But the *rubbee*, which is by far the more valuable, requires water when the rivers are at their lowest, and rain is always uncertain.

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* Doab, *do* (two), *ab* (water). Country between two rivers.

263. After the above explanation, we may now proceed to describe the simplest kinds of canals used in Upper India, which are generally known as *Inundation Canals*, of which there are many existing along the borders of the Punjab rivers, by which the *khadir* or low land is irrigated. Cuts are made from the river inland, for a certain distance, and are then carried in a direction generally parallel to the fall of the country, or the course of the river. By these, when the latter is in flood, the autumn crop is watered. But, in the cold season, when the river is low, the canals run dry and the spring crop thus derives no benefit from them. During that time of year, therefore, laborers are employed to clear the canals of the silt which was left by the waters in their beds or heaped up at their mouths, varying from 1 to 6, or even 10 feet in depth. The irrigation is carried on by means of branch canals leading from the main one, whence the water is carried by minor channels on to the fields. When the levels do not admit of surface irrigation, the water is raised from the canal itself by the Persian wheel, or a temporary dam is placed across the channel to raise the level. Many of these canals have been made for the last 300 years, and are still in good working order, though kept so only by continual labor; their course is very crooked, following every winding of the ground, having been, in fact, laid out without the use of levelling instruments. No fee or tax is levied for the use of the water, but in general, the zemindars through whose lands these canals run, are bound to find laborers to keep them in repair (who work either *gratis* or merely receiving their food), with occasional pecuniary assistance from Government. The main channels vary in length from five to fifty miles, but they are generally too narrow for navigation.

There are no works at the head to control the supply of water, for the course of the river is so uncertain, that it may completely desert the head, and the water may have to be brought in by a new mouth excavated for that season, which again may be useless in the next, or the bank of the river may be cut away to such an extent as to involve the head works in its fall. Under any circumstance, there is always a considerable deposit of silt at the head, which would naturally be increased by anything in the shape of a dam.

The silt excavated from the bed during the cold season, is usually heaped up close to the edge in rough spoil banks, and is constantly falling in, while the tortuous course of the channel also causes large deposits of silt at the bends. The accumulation is still further increased by the water having no exit at the tail of the canal, which usually terminates in a series of small channels in the middle of the district. The labor of clearance thus becomes a heavy annual charge or draw-back on the benefits received from the water, and the numerous deserted channels in various parts of the country show that, without such labor, these canals would soon silt up and become useless. But, in spite of all defects, they are highly prized by the people, and the Government has, at different times made large grants of money for improving some and opening out others.

Their nature and the direction which such improvements should take, will appear further on, as we treat of permanent canals. They may briefly be said to be, straightening the course, thorough clearance of the channel with due attention to the slope of bed, improvement of the banks and proper disposal of the spoil earth; and, finally, where feasible, establishing a control over the water at the head, and giving it a free outlet at the tail, of the canal.

264. The following paragraph is extracted from a Memo. by Lieut.-Col. Anderson, R.E., on Irrigation in general, and Inundation Canals in particular:—

Irrigation by means of canals is chiefly applied to tracts of country which have been formed by the gradual deposit of alluvial matter, from rivers in a state of flood. The deposit from the inundation begins to take place at the points where the velocity of the stream is checked; and this being along the margin of the channel, an inundation of the country through which a river passes, will leave behind it a stratum of silt in the form of a wedge, the thick end of which is on the river bank.

In the course of time, successive annual inundations will thus have formed a slope away from the banks, resembling the glacis of a fortification. The width of this slope, will vary according to the nature and size of the river. It may be only 200 or 300 yards, and be perceptible to the eye, or it may extend to the distance of many miles.

The feature above described is not only to be found along the main channel of a river, but also along its branches. No very extensive tract of country has been formed by the inundation and consequent deposit from a single stream. On the contrary it must have been the work of many.

The channels of all rivers, unless when confined by rocks, have been more or less liable to change their course. By referring to a map of any Delta, the reader will observe that the characteristic of the Delta form, is that a river as it approaches the sea, should split up into two or more branches or arms, which again may be subdivided into smaller ones. Each branch has a tract of country within its influence, and serves to extend the area of alluvial deposit, either by raising its banks, or by extending the Delta seaward.

It is a common occurrence to find dry beds of rivers in alluvial plains, possessing all the characteristics of the existing channels. In some cases channels may be found of such capacity as to show without doubt, that they are deserted beds of the main stream; in others there may be indications of a partial and gradually diminishing supply having reached them, which, by successive annual deposits, has curtailed their section to such an extent as to admit of their being adapted as irrigation channels, or if left entirely in their natural state, such channels may be silted up completely by successive deposits from flood water, and by drifted sand and dust, until they may be no longer perceptible, and all that is left to mark their course is a ridge of high land.

It will thus be seen that an alluvial plain (so called) is not made up of an equable deposit of alluvial matter to the right and left of the main channel of a river, but on the contrary by that from a number of channels, some of which may subsequently be obliterated. The fall of the country also, instead of only following the course of the main channel, will be affected equally by all the others. Intermediate between the channels, the ground will be low, and the line formed by the intersection of the two planes sloping away from their respective banks, will evidently indicate the course in which the drainage from those plains will tend to flow. Such lines will be found also on the extreme boundaries of a Delta,—receiving on one side the drainage of a portion of the Delta, and on the other that of the country independent of it.

After these remarks it is time to explain that the irrigation of a tract of country is based on very simple principles. Supposing that a supply of water is required for the land near the bank of a river, which has ceased to over-flow it, but which may rise to the lip of the channel, then as the country falls away from the river, it will be readily understood that a cut through the bank will give the means of irrigating the ground beyond. This may be considered the simplest form of irrigation. Again, if the surface of the river falls so considerably below the lip of the channel, as to be incapable of supplying water to the ground at a distance, by means of a cut carried at right angles to the course of the river, the difficulty may be surmounted by excavating a channel in an oblique direction; for the course of a river is never straight, and an artificial channel may be formed in a straight line, which will carry the water to a higher level, than that of the surface of the river at any point opposite to it. For every mile of its course, it thus gains something on the surface level of the river, and it becomes a matter of simple calculation to find how far it will have to be carried, before the water issues on the surface. For instance, if the fall of the river surface is one foot per mile, but with a tortuous course of one half more than the direct line, an artificial channel with a fall of one foot per mile, running parallel to the general course of the river, that is from point to point of curves, will for every mile of cutting gain six inches on the river. So that if the surface of the water at the head of the cut were five below the lip of the channel, it would gain that amount on the river in ten miles.

If the cut were excavated in ground on the same level as that on the margin of the river, the water it carried would then come to the surface and be available for irrigation; but as the ground falls at right angles to, as well as with, the course of the river, the required level would be attained by a cut less than ten miles in length; or if the fall along the cut, were less than one foot per mile, say six inches per mile, the water would come to the surface in five miles, or less according as the ground might be level, or slope off in the direction of the cut.

It will be readily understood that the high ridges and the old channels, above described, indicate the most suitable alignment for a series of Irrigation channels. The object would be to conduct the water from the river to the crest of such high lands, and then, for the channels along them, to arrange as far as may be practicable, that the excavation, shall be no more than sufficient to furnish the material required for the embankments, which should retain the water at as high a level as possible, consistent with their stability. If the depth of water admitted into the head of the main channel is materially less than what is due to the river at its full height, the depth of the excavation at the head will increase in proportion to the difference; and it will then be an object, in order to make the cutting as inexpensive as possible, to carry the line of the channel through low ground, until the water would flow on the surface. The irrigation limit is then reached, and the channels should be continued along the highest ground, that will allow of the water continuing on the same level with it or above it, as may be found most suitable for the locality. If the ground were level on both sides of the channel it would in many cases be indispensable to have the surface of the water above it; but in the other hand the soil may be ill-adapted for withstanding pressure, or for preventing percolation; and to avoid the occurrence of breaches, it may be desirable, to keep the height of the embankments within very moderate limits.

Heads of Inundation Canals.—A channel opening direct from a river, and unprovided with a sluice or other regulating work at its head, is subject to the two following disadvantages. It is subject either to have its supply increased to an inordinate extent during high freshes, or to have it cut off altogether. In one case the current of the river may set on the mouth of the canal, or on the bank above it. If the soil is liable to erosion, it will be cut down and washed into the canal: the head of the canal itself would be enlarged; and such destructive action would only be limited by the duration of the fresh. The greater the fall of the canal in this case the greater the evil. Or, on the subsidence of the higher freshes, the stream may have moved to the opposite bank of the river, leaving a mass of sand banks between it and the head of the channel, which it would be impossible to cut through in time to replenish the supply. In this case the *less* the fall of the channel the greater the evil. Both the above contingencies must be common in all Irrigation channels which are opened from a river with a shifting bed. In the latter, a temporary bund may in some cases be effectual in replenishing the channel, but it has generally to be constructed before the freshes have finally ceased, and is very liable to be destroyed just as it is completed. Though a new head may be formed through the sand banks for the next season, it is next to impossible to cut through them at the close of the rains, with a falling river, and when the water under the surface of the sand bank stands on a higher level than that of the river.

The violent action on the mouth of the channel when the river sets against it, may be checked by revetments, groynes and such like defences, but they must also have the effect of diverting the action of the stream from its natural course, and thus tend to throw it off towards the opposite bank. Supposing that there were no other difficulties to surmount but the two I have specified, they might be overcome by the construction of a head sluice, with defences against encroachment, and of a groyne running from the opposite bank, so as to force the stream of the river to pass alongside the head sluice. In many cases however the construction of such a groyne would be impracticable. The river might be too large, suitable material not procurable, and the expense of maintenance of the groyne itself, and the river defences which it would necessitate, would be too great, to be justifiable, unless the channel were of very high importance,—and in that case a dam or anicut across the river would be more efficacious than a groyne.

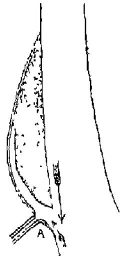
It is an object of high importance to fix the heads of channels in positions where they will be least liable to silt up, in order that they may have no greater obstacle to contend with, than what is inevitable,—that is, the chance of an insufficient height of the freshes. Unfortunately, unless in a river which flows in a permanent channel, it is impossible to find a site, where the head of an irrigation channel will not be exposed to silting. The advantages of any sites will only be relative: no general rules, either, can be laid down for selecting them; so much must depend on local peculiarities that what might be sought after on one river, would have to be carefully avoided on another. It will depend on the nature of the soil, fall, &c., and the height of the water, whether it is advantageous or otherwise to expose the head of a channel, to catch the full effect of stream in the river. In some places this might be a desideratum, in others it would simply destroy the channel.

I will therefore confine myself to a few observations on particular cases on which I have found channels to be defective or otherwise.

When opened so as to have the stream in the river bearing on the head as much as possible. If the soil is not extremely tenacious, the banks at the head of the channel will be washed down, and the material thus displaced will block up the channel. If the sides of the head are revetted, a great part of the evil may be averted, but it will be found that this will not prevent sand banks accumulating in front of the mouth, and if the stream acts on the bed, a large quantity of material may be carried forward to the lower portions of the channel.

If a canal is opened from a bank which the river shows a tendency to set against and cut down at any point above the head, then there must be evident danger of the canal being choked up by the material which would be washed down.

In the case of a river which is liable to occasion mischief of this kind, the most suitable point for opening a channel is where there will always be a sufficient depth of water without any violent stream acting on the banks. Perhaps the most suitable of all conditions would be if the river passed at right angles to the head of the channel, but as there could be no certainty of its continuing in that direction, it would be better to avoid such a site, and to select one where the water would be comparatively stagnant. For instance, if the river flows in the direction shown in the adjoining diagram after receding from a curved channel, which it may have formerly cut for itself by encroachment on the bank, or if A be the tail of a creek or arm of the river which leaves the main channel at some point higher up, there will be a backwater there, and, although the stream may pass over the sand bank or island with considerable velocity in the freshes, it will be less than that of the main stream, and less likely to do mischief. The point A would therefore be a good site for the head of the irrigation channel. It must be observed that the backwater may be of recent formation, and that its mouth may tend to advance down-stream, so that care should be taken to have the head of the channel sufficiently low down to guard against the contingency of the channel in front becoming dry, and at the same time not so low as to bring it within the influence of the main stream.



It will frequently be found that there is no eligible site for the head of a channel in the bank of the river in an interval of many miles. The river may have receded towards the opposite bank, leaving a mass of sand banks between it and the point where the channel may be required. In such cases, however, there is generally the dry channel of the river or of a branch of it, running along the foot of the bank, and it may be necessary to follow it up to its head, and perhaps to clear it, in order to make use of it as an artificial channel. The head of such a channel, if there is any choice on the matter, should be selected on the same principle as that of an artificial channel, care being taken to hug the bank as much as possible, or at least to remove all the soil excavated, to the side which will be furthest from the action of the stream in freshes, or it would otherwise be washed into the channel.

In some cases there may be no alternative, but to cut through the head of a sand bank with the knowledge that the effect of any excavation will only be temporary. There will then be great danger of the supply failing when the river subsides, and should it do so, there will be no remedy, unless it may be that the creek leading to the canal may be large and may derive a partial supply, though on too low a level to suffice for the wants of the canal. In this case, a bund across it immediately below the head of the latter may be of some service.

Head Sluices.—If the canal is to be furnished with a sluice, it should be constructed as near the head as is consistent with its stability. If the bank of the river, and the head of the channel can be rendered secure against injury at a moderate expense, by means of revetments or groynes, the efficiency of the canal would be much promoted by constructing them; but if the river is not tolerably permanent, and there is the likelihood of the canal head being left at times high and dry, with the necessity of opening a new head at some point higher up or lower down the river, the sluice and works connected with it would be rendered useless. When however there are no such disadvantages to contend against, it would seem highly desirable that every channel should have its head sluice, in order that any excessive supply of water may be prevented from entering. Unless it is built at the head of the channel, this advantage cannot be obtained without the inconvenience of a deposit of silt in the channel between the head and the sluice. The extent of this will of course depend on the height of the water, and the time during which it is held up by the sluice. If the interval between the sluice and the head is considerable, this evil, would be serious; and in many cases, it would be better to construct the sluice at the head, with the chance of its being destroyed. This, however, is a question to be decided separately for each case on its own merits. If a sluice is required to prevent inundation, and if disastrous effects would ensue from its destruction, it might be advisable in such cases to have a second sluice in reserve, at a sufficiently safe distance from the head.

Slope of Bed.—Where the fall of the country is tolerably uniform, the slope of the bed of the main channel should be less than that of the branches, which again should be less than that of the minor channels and cuts. The object of this is to secure as far as possible a uniform velocity, so that the alluvial matter held in suspension may be carried on from the head, and deposited uniformly over the lands irrigated.

As to the actual fall which should be given to the main trunk of a canal, apart from the consideration of expense or in fact any considerations, but that of the maintenance of the channel in good working order, I would name 6 inches per mile, in preference to any other, for alluvial soil of moderate tenacity—on the supposition that the depth of water will be from 6 to 10 feet, and the width considerable (say

100)—being nearly the same that I have observed has been adopted by channels in their natural state, in similar soil. I would by no means insist on this being the best fall in all cases.

I assume the slope of bed to correspond with the slope of surface, but it may be desirable to cut down the head of the canal, so as to yield a smaller slope of bed, in order to obtain a supply of water at an earlier date in the season. But the bed always tends to follow the slope of surface, as will be obvious from the consideration, that if the depth is greater towards the head than it is at some point lower down, the velocity (supposing the width to be the same) will be less, and silt will consequently be deposited until the velocity throughout becomes uniform. Such a diminished slope at the head must therefore render necessary a considerable annual clearance.

On the assumption that a surface fall of 6 inches a mile, or, say 1 in 11,000, is suitable for the main channel at starting, with a width of 100 feet, I proceed to show the rate at which the fall should be increased as the supply becomes less.

Let us suppose that branches are drawn off, taking a certain proportion of the water, and that the width of the main channel is reduced by successive degrees to a width of 80, 60, 40, and 20 feet, and that the depth is reduced successively to 5½, 5, 4½ and 4 feet, but that the velocity throughout is maintained, at what it had at starting with a width of 100 feet, depth 6 feet, surface fall 5·7 inches per mile,—namely, 2·1 feet per second. By means of the hydraulic formula, I find the fall of surface required in the different cases will be 6·4, 7, 7·9, 10·3, inches per mile. From the terminus, let a channel leave with a depth of 3 feet and width of 10 feet reduced after consumption of a portion of the supply of water, to a width of 6 feet and depth of 2½ feet; the velocity to be the same as before. The fall required for these channels will then be 14·8 and 19·5 inches a mile; and if we suppose the length of each of the first mentioned channels, or reaches of channel, to be 10 miles, and that of each of the two last to be 5 miles, the whole fall from the head will be somewhat more than 45 feet, and the whole distance being 60 miles, the average would be 9 inches per mile. If the fall of the country did not admit of so high an average, it might be easily reduced by maintaining a greater depth in the channels and diminishing the width. If for instance, in the case above-mentioned, the depth for 50 miles had been maintained at 6 feet, the total fall required would only have been 26 feet, or on the average 6¼ inches per mile.

The above will be sufficient to indicate the mode in which the slope of the channel should be regulated in order to prevent accumulations of silt. In practice a canal is never perfectly aligned on this principle, but unless it can be shown to be defective, as I have no reason to think can be done, every endeavour should be made to adhere to it, in designing a system of Irrigation works, so far as local peculiarities and other circumstances permit.

The accumulation of silt in channels, particularly in the main channel, is not only a serious impediment to maintaining a supply of water till the crops are matured, but the clearance may be enormously expensive. Even if the silt cannot be carried on to the fields, as in a perfect canal, at least one step in advance is gained, if it is prevented from accumulating in the main channel; for the maintenance of the supply in it is the most essential point, and if there are deposits in the branches only, it may be possible to clear them in turn, without cutting off the supply from the river; or if this might not be feasible with the branches, it would be so at all events with the smaller irrigation channels; and it would not only be advantageous to throw on the silt to them, and to clear them in turn, without cutting off the supply of water from the branches, but the clearance would evidently be much less costly from them, than it would be from the larger channels.

When the fall of country is so gentle as not to allow of the fall of the channels being gradually increased from 6 inches a mile, it would be necessary to reduce the initial slope somewhat. A very slight reduction, would, as it affects the whole of the channels onwards, in the aggregate, amount to something considerable.

If, on the other hand the fall of country be too great, the initial slope may be increased, with, if necessary, a reduction in the depth of water; or if the fall of country is rapid at first and afterwards more gentle, the desired result may be attained by constructing perpendicular drops at intervals.

Any change of direction causes a certain loss of velocity, and the water thrown into branches and minor channels would lose velocity, in passing through the head-sluices, unless they possessed the full water-way of the channel. Due allowance would have to be made for this by adding somewhat to the slope at the heads of the branches and channels.

The principle above described of the necessity of keeping up the velocity to the point of the delivery of the water, is so obvious, that it must have occurred to every one, who has had much to do with Irrigation works; and I should not have thought it necessary to dwell upon it, at such length, had I not reason to believe that it is very much lost sight of in practice.

CHAPTER XLVIII.

PERMANENT CANALS—SOURCE OF SUPPLY—AMOUNT OF WATER REQUIRED—SLOPE OF BED—SECTION OF CHANNEL—ALIGNMENT OF CANAL.

265. We now come to Canals of Permanent Supply, of which the greatest examples now in use are the Ganges, Baree Doab, and the East and West Jumna Canals.

The first point to be considered in designing such a work is, *the Source of Supply*. This will always be a river carrying a perennial stream (in Northern India fed by the snows of the Himálayas) ; and the only question is, at what point in the river's course we shall take off our supply, *i. e.*, fix the head of our canal ?

From what has been said above (p. 308) it will appear that this point must be high up on the river's course, so as to obtain plenty of command of level, and get on to the high ground without much heavy digging ; and it will generally be found, that for this purpose, it is necessary to go either to the spot at which the river finally leaves the hills to flow through the plains, or to a point, at any rate, not far below that spot. Moreover, at this point the water (except in freshets) is pure and free from silt, the great enemy of canals, and the course of the river is restricted within narrow limits, so that by dams thrown across the river bed, we can easily divert the water into our new channel.

The above considerations are so important, or rather, peremptory, that they outweigh the disadvantages of the arrangement, which are, indeed, very serious. For, the country so close to the hills having generally an excessive fall, and being, morever, intersected by hill torrents, the carrying of the canal through such irregular ground entails serious difficulties, which require the greatest engineering skill and a large expenditure of money, to overcome them.

The selection of the exact spot for the head of a canal is a task requiring much careful consideration. The chief principles by which the selection will be determined, besides those already indicated, will appear as we proceed

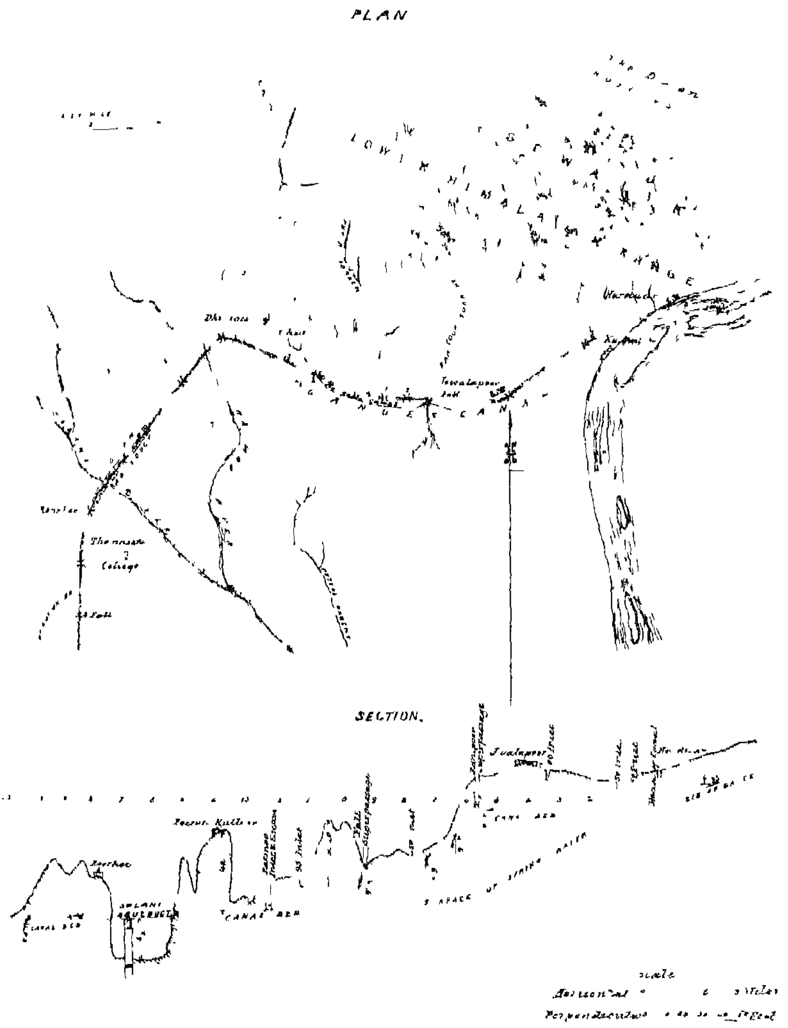
266. The next question is, *How much water do we want?* for on this depends the size of our canal; and this is determined partly by the area of land to be irrigated, and partly by the quantity of water that can be obtained from the river when at its lowest. In Northern India, however, the area of land requiring irrigation being practically unlimited, the question becomes, "How much water is available from the river or source of supply at its lowest?" For though at first sight it might appear feasible to make the canal channel large enough to carry an extra quantity of water when the river had plenty to spare, experience has proved that as this extra water would be available for one crop only and that the less valuable one, the advantage of this arrangement would rarely compensate for the extra cost required to be incurred on the channel and masonry works. The minimum discharge of the Ganges is reckoned at 8,000 cubic feet per second at Hurdwar, where it leaves the hills, and the Ganges Canal channel is made to pass 6,750 cubic feet of the above supply. It might, at first sight, be imagined that the abstraction of so large a quantity of water from a navigable river would seriously interfere with the navigation below, but, the discharge above noted is only that of the *visible* stream. The water above sinks down through the permeable strata of the bed and reappears below the point where the canal is taken off, and experience has shown that in the lower parts of the river, the interference with navigation caused by the large amount of water abstracted above for the canal, is practically not felt

It is evident that the effective work of a cubic foot of water discharged from the canal, for irrigating the land, must depend upon variable data, such as the nature of the soil and the crop, the distance the water has to be carried on to the land from the main channel, the humidity of the atmosphere, &c.

The average assumed for drawing out the projects for the Baree Doab and Ganges Canals (derived from data afforded by the Jumna Canals) was, that each cubic foot per second of discharge was capable of actually irrigating 218 acres; and reckoning that for each acre actually watered there would be two other acres either lying fallow or being watered from wells or rain, then each cubic foot would represent 654 acres, (say one

PLATE LIII.

NORTHERN DIVISION—GANGES CANAL.



square mile,) of culturable land, more or less dependent on the Canal. In the Soane Canal Project (1861), Col. Dickens reckons three-fourths of a cubic foot of water per second, for every square mile of gross area.

By the Report of the Superintendent General of Irrigation, for 1860-61, each cubic foot on the Eastern Jumna Canal, actually irrigates 296 acres. In Madras, one cubic foot per second of discharge is reckoned sufficient to irrigate 40 acres of rice, or 100 acres of sugar. Our canal data are as yet too imperfect to be able to speak precisely on these points, and it is evident that the conditions are very varying. So long as the present system is continued of paying for irrigation according to the area watered, and not according to the amount of water taken, it is evident that there will be great waste.

The method of calculation adopted by Sir P. Cautley in the Ganges Canal, was to reckon the expenditure of water per lineal mile of canal which from practical data was taken to be 8 cubic feet as the maximum. In the Sutlej Canal project, 6 and 7 cubic feet have been taken. This, however, presupposes that the main and branch lines have previously been fixed upon; it is a very convenient form of calculation, as it enables us to regulate the size of the channel along the whole course of the canal, diminishing it as the water is gradually expended.

If the canal is to be a navigable one, a certain minimum depth must be assumed everywhere, so that the amount of water required for that minimum must be allowed over and above the quantity to be expended on irrigation. On the Soane Canals, 600 cubic feet per second have been set apart for navigation alone; on the Baree Doab Canal, 180 feet; on the Ganges Canal, 400 cubic feet.

A large area of the land through which the canal takes its course may be unfit for cultivation. The soil may be bad or swampy, or it may be reserved for forest or grass preserves, or occupied by towns or cantonments. All this has of course to be taken into consideration in fixing the area actually available for irrigation, whence the amount of water required must be determined.

Suppose we desire to irrigate a particular district, say 200 miles long and averaging 40 miles broad, lying between two rivers by cutting a canal from one of them, and carrying it along the watershed of the country. The total area of such a district would be 8,000 square miles. Now of this our maps would show us (say) that 1,500 square miles were *khadir* land, which could be irrigated by wells or by small canals cut from the river, leaving 6,500 square miles of *bangur* to be provided for, from which another 1,500 would very likely be deducted for town sites, swamps, forests, &c., leaving 5,000 square miles actually requiring irrigation. At the rate of 1 cubic foot per square mile, this would require a canal with a minimum discharge of 5,000 cubic feet per second. Or, if we reckon 8 cubic feet as required for each lineal mile, we should require 625 miles of canal; but, practically, the lines of irrigation would be first arranged on the map from the levels, and thence the amount of water would be determined and might be compared with the area calculation.

Should the amount of water required not be obtainable from one river only; it is possible it might be feasible to take a supply from both. If not, then the greatest amount that can be obtained from one when the river is at its lowest must, for the reasons above given, be assumed for the calculations.

267. *Width of Channel.*—The proportion of depth to width on the Western Jumna Canal, being that which the stream has in course of years formed for itself, was found by a series of trials to be about 1 in 13. On the Baree Doab Canal, the proportion fixed in construction was 1 in 15; for the Sutlej Canal, 1 in 14. It is evident, if the canal is to be navigable, that the minimum of width must always be sufficient to allow of two boats passing each other, while a minimum of depth (usually 2½ feet), must also be allowed to float the boats.

The side slopes of the canal channel will be arranged generally according to facilities for excavation, for unless the slopes are made very flat, or are turfed at a great expense, the action of the water will in ordinary soil quickly cut them to the shape at which they will ultimately stand firm.

268. Having determined the quantity of water, and fixed the proportion of depth to width, and a minimum for both, chiefly with reference to navigation facilities, there yet remains a very important question to be determined before we can devise the section for our channel, that is the *Slope of the Bed.*

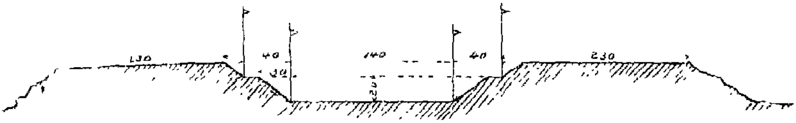
If this slope is too great, the bed of the canal will be torn up, and the foundations of all bridges and other works will be endangered. Besides which, the difficulties of navigation against the stream will be largely increased.

If, on the other hand, it is too small, a larger section of channel will be required to discharge a given quantity of water, and, as will be explained further on, many additional works will be required in the shape of Falls,

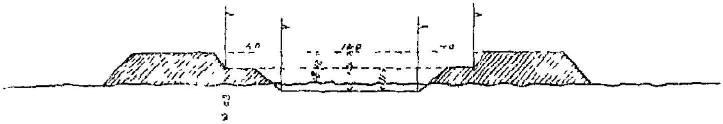
VARSHA

CROSS SECTIONS—GANGES CANAL

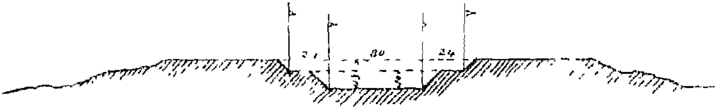
From Myapoor to the Rampoor Torrent



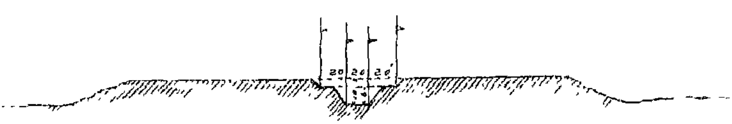
Section of Canal at Moradnuggur



Section at the 180th Mile



Section near the tail



Locks, &c.; there will also be danger of silt being deposited in the bed, or of the stream being choked by the growth of aquatic plants.

It is therefore necessary to steer clear of both extremes; but it is not always easy to do so, and in general a compromise has to be made. Moreover, as the velocity increases very rapidly with the depth, it is evident that a slope of bed which might be a very proper one for water of a certain depth, would be too great if it were necessary to increase that depth so as to throw an extra supply into the canal.

The minimum velocity required to prevent the deposit of silt or the growth of aquatic plants may be said to be about 1½ feet per second, so that if a minimum of depth be fixed, we can find the minimum of slope necessary to secure any given discharge. Under ordinary circumstances this may perhaps be fixed at 6 inches per mile, though it is occasionally even lower than that.

The maximum is not however so easily fixed. It must in the first place vary with the nature of the soil of the bed. A stony bed will stand a velocity of 3 feet per second, while sand will be disturbed by a velocity of 6 inches. Again, the maximum velocity at which a boat can be navigated against the current at a profit is evidently a very intricate problem, depending on such varying data as the moving power employed, whether steam, animals, or men; the description of boat, value of the cargo, &c. And without such a calculation for any particular locality, it is evidently impossible to determine whether it is worth while to undergo a heavy additional expense in reducing the slope (and, consequently, the velocity) of an irrigating canal in order to fit it better for navigation purposes. If the saving thus effected on the total traffic annually conveyed would defray the interest of the increased capital required for the proposed reduction of slope, then it would doubtless be desirable to make that reduction, looking at the question from that point of view only. But there is a limit to the reduction of slope beyond a certain minimum, as explained above, owing to the paramount necessity of preventing the deposit of silt in the canal channel, and though 6 inches per mile has been given as the minimum limit which would not under ordinary circumstances interfere seriously with navigation, still it must depend of course on the fall of the country and the nature of the soil, and so difficult is it often found to combine the requirements of the two purposes, irrigation and navigation, that it has been seriously proposed to provide for the latter by separate still water channels, made alongside the running canal itself.

In some experiments made on the Ganges Canal, it was found, that at a velocity of 3·76 feet per second, the water just ceased to cut away the bank, and slightly deposited silt. With the ordinary soil of the plains of the N. W. Provinces, which is a light friable clay, and taking everything into consideration, perhaps 3 feet per second may be taken as a safe maximum velocity for these canals.

The upper part of the Baree Doab Canal has a fall of 4·2 feet per mile over a bed of shingle and clay, but navigation at that point was not required.

The Ganges Canal starts with a fall of 2 feet per mile, which soon diminishes to 1·25 feet, and this latter may be said to be its ruling gradient. With a depth of water not exceeding 5 feet this gives a very manageable velocity, both as regards the safety of the works and the navigation *down*-stream. For *up*-stream navigation it would be advantageous to reduce it. But when 6, 7, or 8 feet of water are thrown into this canal, the velocity due to the above fall is doubtless too high.

In the Sutlej Canal project, Captain Crofton has fixed upon 2½ feet as his minimum depth of water at full supply, and has arranged his declivities of bed so that the calculated mean velocity of current shall in no case much exceed 3 feet per second.

For the Soane Canals, the velocity has also been fixed at about 3 feet per second (2 miles an hour), the side slopes being 1½ to 1, and a bottom width equal to the depth plus one, squared, in feet.

269. The following Memo. on this important subject from Major Crofton's report on the Ganges Canal will be found very valuable:—

> *Velocities of current.*—In a portion of the channel of the Eastern Jumna Canal lying in the old bed of the Muskurra torrent, where the current seemed perfectly adjusted to a *light sandy soil*, Major Brownlow, the Superintendent of the Canal, found the mean velocities of the surface to be from 2·38 to 2·28 feet per second, or mean velocities (multiplying by 0·81), 1·928 to 1·847 per second.
>
> In the lower district of the same canal, near Barote and Deola, the maximum surface velocities with a fair supply were found to be 2·817 and 2·507 feet per second, or mean velocity of 2·282 and 2·03 feet per second. Silt is constantly being deposited here; the soil is similar to that below Sirdhanna on the Ganges Canal.
>
> About 1000 feet below the Ghoona Falls, on the same canal, in *very* sandy soil, with nearly a full supply of water, I found the maximum surface velocity to be 3·077 feet per second, or mean velocity 2·492 feet per second: no erosion from bed or banks, except when a supply, much in excess of the maximum allowed, is passing down.
>
> Below the Nyashahur bridge on the same canal, where the soil is very similar to that between the Myapoor and Kunkhul bridges on the Ganges Canal, clay shingle and small boulders, Lieutenant Moncrieff, R.E., the Officiating Superintendent, found

the mean surface velocity to be 6·751 feet per second, or the mean velocity about 5·165 per second.

The same officer observed the surface velocity at some distance below the Yarpoor Falls in the new centre division channel of the Eastern Jumna Canal, and obtained a mean of 3·957 feet per second, or about 3·205 feet per second mean velocity through entire section. The soil here is light and sandy, and the channel has been both widened and deepened by the current.

In one of the rajbuhas (or main water-courses) of the same canal, I found weeds growing in the bed and on the sides with a maximum surface velocity of 2·12 feet per second, or mean velocity (V) of about 1·717 feet per second; the soil is sandy with a fair admixture of clay; silt accumulates to a troublesome extent.

In another rajbuha in the same neighbourhood, I found a surface velocity of 2·38 feet per second, or mean about 1·927 feet. Silt deposits here, but no weeds appear to grow.

In the Muhmoodpoor left bank rajbuha on the Ganges Canal, I found grass and weeds growing in the channel with a maximum surface velocity of 1·724 feet per second, or mean of 1·396 feet.

In the Buhadoorabad Lock Channel, Ganges Canal, weeds appear to grow wherever the maximum surface velocity is 2·38 feet (or mean velocity 1·928 feet per second or under); soil generally light and sandy.

On the Ganges Canal I found velocities as follow:—Below the Roorkee bridge on the main canal, where the deepened bed is covered with silt and erosion from the sides has ceased, the mean velocity in the entire section, with a supply less than the present maximum on the Roorkee gauge by 2 inches, was 2·92 feet per second; the soil sandy with a tolerable admixture of clay.

In the widened channel at the Toghulpoor sand hills, mile 36, the mean velocity, with full supply now allowed to pass down, obtained by calculation from the area of the water section and the discharge observed below Roorkee (deducting expenditure *en route*) was 2·532 feet per second.

In the embanked channel across the Solani valley, with a supply 2 inches under the present maximum on the Roorkee gauge, the mean velocity, obtained by calculation from the area of water section there and the observed discharge through the masonry aqueduct, was 3·04 feet per second. The deepest portions of the channelling out here, I have stated elsewhere, have been silted up.

At the 50th mile, main line, below the Jaolee Falls, with (present) full supply in the canal, the observed mean velocity was 3·059 feet per second. Erosion from the banks has ceased here; silt on the deepened bed, soil sandy.

Above Newaree bridge, 94th mile, in a stiff clay soil with full supply in the observed mean velocity, was 4·117 feet per second: erosion trifling here; no silt deposit.

Observations communicated by Captain Dyas, R.E., Director of Canals, Punjab.—On the Hansi branch of the Western Jumna Canals, silt was deposited with mean velocities of from 2· to 2·25 feet per second. The deposition of silt, however, obviously depends on the quantity and specific gravity of the matter held in suspension by the water coming from above, and the ratio of the current velocities at different points along the channel.

He states, from observations on the channels of the Baree Doab Canal, that in sandy soil "2·7 feet per second appears to be the highest mean velocity for non-cutting as a general rule, for there are soft places where the bed *will* go with almost any velocity;

but those sorts of places can be protected." Again, "bad places might be scoured out with a mean velocity of 2 5 feet per second, but better soil would be deposited in place of the bad with a slightly smaller velocity than 2·5 feet; and as the supply is not always full, there would be no fear of not getting that slightly smaller velocity very frequently. The good stuff thus deposited would not be moved again by any velocity which did not exceed 2·5 feet per second.

In "Neville's Hydraulics," 0·83 or 1·17 feet per second are mentioned as the lowest mean velocities which will prevent the growth of weeds. This, however, will vary with the nature of the soil; vegetation also is much more rapid and vigorous in a tropical climate than where Mr. Neville made his observations.

In Capt. Humphrey's and Lieutenant Abbot's reports on the Mississippi, 1860, it is mentioned that the alluvial soil near the mouth of the river cannot resist a mean velocity of 3 feet per second; and that in the Bayou La Fourche, the last of its outlets, which resembles an artificial channel in the regularity of its section and general direction, and the absence of eddies, &c., in the stream, the mean velocity *does not exceed* 3 feet per second, and the banks are not abraded to any perceptible extent

From the foregoing and other observations, which it would encumber this paper too much to place on record here, and taking into consideration that the higher the velocity the less the works will cost, I think the following may be taken as safe mean velocities with maximum supply in the Ganges Canal channels.

1. In the Ganges valley above Roorkee, 3 feet per second.
2. In the sandy tract generally between Roorkee and Sirdhanna, 2·7 feet per second.
3. In very light sand, such as that met with at the Toghulpoor sand hills, not higher than 2·5 feet per second.
4. And for the channels south of Sirdhanna, 3·0 feet per second.

On the branches the same data to be assumed according to similarity of the soil.

There are soils, as Captain Dyas has noted, such as light quicksand, which will not stand velocities of even 1 foot or 1½ foot per second, but these are never found to any great extent in one place: erosion there can only have a local influence, and such places can be protected at a trifling expense. It is channelling out on long lines which is to be feared.

270. From the above considerations, therefore, we can now determine the section of the canal channel by the help of proper mathematical formulæ.

Let D = the discharge at any point in cubic feet, A the area of the channel section in square feet, and V the mean velocity, at that point in feet per second, then of course D = AV.

Now to find V, many formulæ have been given by Dubuat, Neville, and and other authorities on hydraulics; some of which are very elaborate. Major Crofton uses (from Neville) $V = C\sqrt{\frac{d}{s}}$, *d* being the hydraulic mean depth,* *s* the denominator of the fraction denoting declivity of bed, the numerator being unity, and C a co-efficient, which he takes at 90 for velocities up to 4 feet per second, and 93 for high velocities, such as those of hill torrents, &c.

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* Found by dividing the area of the channel section below the water line by the water contour (*i. e.*, the length of the bottom and sides of the section).

Dwyer's formula $V = \cdot 92 \sqrt{2ds}$, d being the same as above, and s the slope of the bed in feet per mile, is recommended as simple and sufficiently correct for all ordinary cases of canal discharges.

271. In canals actually running, the velocities may be also determined by direct observation, as in the case of a river [see above, para. 84].

The observations for discharge of the Ganges Canal channels taken for the purposes of Major Crofton's report were obtained as follows :—

Two cross sections of the stream were taken at a uniform distance apart of 200 feet, the depth of water being measured at every 10 feet or less along the width of each section.

The velocities were obtained by noting the times of transit at several points in the width of the stream of floats from the upper to the lower section; these floats were made of painted deal rods about an inch square, loaded at one end so as to float nearly vertically and pass as close to the bed of the channel as possible without touching, their upper ends projecting a few inches above the water's surface. They were found in every case to float in a line closely parallel to the thread of the current. A very near approximation, it is evident was thus obtained to the mean velocity in the vertical plane traversed by each. A correction for the small height of the end of the float above the bed was applied to each velocity before using them for the calculations of discharge, viz. :—

$$C \text{ (or multiplier of velocity)} = 1 - 0{\cdot}116 \left\{ \left(\frac{D - D_1}{D} \right)^{\frac{1}{2}} - 0{\cdot}1 \right\}$$

where

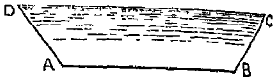
$D =$ depth of water.

$D_1 =$ length of rod immersed.

This was given in the report on the Mississippi by Captain Humphreys and Lieutenant Abbot, as obtained by Mr. Francis, in his experiments at the Lowell Water-works, where velocities of current were observed in a similar manner to the above.

Velocities were observed on the Ganges Canal and elsewhere, also by a current meter of similar construction to that known as Woltmann's hydrometer, as well as by surface floats, but no method yet tried seems so satisfactory as that of the floating rods. The declivity of the water's surface was also in most cases observed for the purpose of comparison and obtaining reliable co-efficients for calculation.

272. To illustrate the foregoing, let us suppose that in the instance above given at p. 317, 4,000 cubic feet were available as the minimum discharge, and that we determined to make our channel accordingly. We will fix on a fall of 1·5 feet per mile as the ruling slope, and excavate the channel with side slopes of 45°; then to find the necessary bottom width AB of the channel at the head; let the depth be to the width as 1 : 15 and call the depth x, so that $AB = 15x$, then $CD = 17x$, and the area of the section $= 16x^2$, also as $AD = BC = \sqrt{2x^2}$, the wet contour $15x + 2x\sqrt{2}$, and the hydraulic mean depth $= d = \frac{16x}{15 + 2\sqrt{2}}$; and from Dwyer's formula, $V = \cdot 92\sqrt{2ds} = \cdot 92\sqrt{3d} = \cdot 92\sqrt{\frac{48x}{15 + 2\sqrt{2}}} = 1\cdot 5\sqrt{x}$, and discharge $= D = 4{,}000 = 16x^2 \times 1\cdot 5\sqrt{x} = 24\sqrt{x^5}$; hence $\sqrt{x^5} = 166\cdot 67$, and $x = 7\cdot 74$, therefore $15x$ the bottom width $= 116$ feet. Or we may assume a value for x, and by trials approximate of the real value. Or, the depth of digging may be determined for us by our levels, which would also determine the bottom width, if it is to be 15 times the depth. And if these dimensions would not suffice for the required discharge we should have to alter the ratio or else increase the slope of the bed.

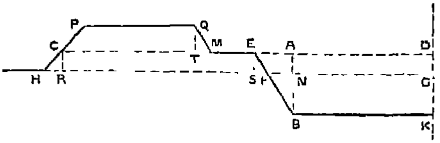


273. The section of the water channel and slope of the bed being thus determined, it is evident that the surface of the water may either be *within soil*, (as it is termed,) that is below the natural surface of the ground, or above soil, when it will have to be retained by artificial embankments. If, not merely the surface level, but the whole body of water is above soil, the embankments must of course be very massive and may require to be puddled to render them water-tight. In the great Solani embankment, the water is retained within a solid masonry revetment on each side, backed up by an earthen bank averaging 16 feet high and 40 feet thick.

Although the water being thus raised above soil greatly increases the facility of irrigation by its command of level, it is evident that the construction of such embankments involves great expense, and that if any breach occurs the damage done will be very great.

274. The most favorable conditions are obviously when the canal water is partly within and partly above soil, so that the earth excavated from the channel just suffices to build up the banks, while there is sufficient command of level for all irrigating purposes; and the nearer this can be approximated to, the more perfect will the canal be. The following would be such a section:—

Let $2a$ = width of canal at foot B.
d = depth of canal AB.
x = required depth of digging.
Let A = area of bank above EC,
B = „ canal be below DE,



Then whatever be the position of the natural surface, A and B are constants.

What we wish is to determine the depth BN so that the area, BFGK shall = EFHPQ.

i. e, B − EFGD = A + EFHC

i. e., $\text{B} - \frac{\text{ED} + \text{FG}}{2} \times (d - x) = \text{A} + \frac{\text{EC} + \text{HF}}{2} \times (d - x)$

i. e, $\frac{d - x}{2} \left\{ (\text{ED} + \text{FG}) + (\text{EC} + \text{HF}) \right\} = \text{B} - \text{A}$ .... (1)

Let EC = h, let α = inclination of EB, β = inclination of HP. Then HR = CR $\cot\beta = (d - x)\cot\beta$, SF = $(d-x)\cot\alpha$. And HF = $h + (d - x)(\cot\alpha + \cot\beta$ ∴ EC + FH = $2h + (d - x)(\cot\alpha + \cot\beta)$.

$$\left.\begin{array}{l}\text{Now ED} = \text{AD} + \text{AE} = a + d\cot\alpha \\ \text{FG} = \text{HG} + \text{FH} = a + x\cot\alpha\end{array}\right\} \therefore \text{ED} + \text{FG} = 2a + (d + x)\cot\alpha.$$

Hence, substituting in (1)

$\frac{d - x}{2}\left\{2a + (d + x)\cot\alpha + 2h + (d - x)(\cot\alpha + \cot\beta)\right\} = \text{B} - \text{A}.$

$\frac{d - x}{2}\left\{2a + 2d\cot\alpha + 2h + d\cot\beta - x\cot\beta\right\} = \text{B} - \text{A}$; $ad - ax + d^2 \cot\alpha - dx\cot\alpha + hd - hx + \frac{d^2}{2}\cot\beta - dx\cot\beta + \frac{x^2}{2}\cot\beta = \text{B} - \text{A}\ \frac{x^2}{2}\cot\beta - x(a + d\cot\alpha + h + d\cot\beta) = \text{B} - \text{A} - d(a + h) - d^2\cot\alpha - \frac{d^2}{2}\cot\beta.$

From which equation we can find x.

Take an example, let $\alpha = \beta = 45°$.

Then $\cot\alpha = \cot\beta = 1$

Let $a = 50$, $d = 8$ feet, $h = 40$. PQ = 25 feet, QT = TM 6.

∴ CM = 37. Then $\text{B} = ad + \frac{d^2}{2} = 432$.A $= \frac{25 + 37}{2} \times 6 = 186.$

∴ Equation becomes $\frac{x^2}{2} - x(106) = 432 - 186 - 8 \times 90 - 64 - 32 = 574.x^2 - 212x = -1148$, whence $x = 5{\cdot}6$.

For sanitary reasons it may be desirable to keep the water as a general rule within soil, but the effect of this will be to increase greatly the cost of the canal—and if, as is often the case, a sandy stratum underlies the superficial clay it is very undesirable to dig down to the former, as much water may thus be wasted by leakage and absorption.

275. *Alignment of the Canal.*—The steps to be taken in fixing the line of the projected canal and in marking it out when approved of, will be similar to those described in the Section on Roads. The gradients have to be duly considered in both cases, though much more carefully in the former The requirements of the different towns and villages, which, in the case of a road have to be considered with reference to traffic, will have chiefly to be viewed in regard to irrigation, and secondarily only for traffic in the case of a canal.

The *obstacles* to be avoided, whether mountain torrents, swamps, hills, &c., are much the same, and the more elaborate methods of overcoming them required for canals, will be described further on.

If no good map of the country exist, one must be made. The next step will be to get a series of cross sections of the country to be irrigated, from river to river, by means of *lines of levels*, from 1 to 5 miles apart, and having a direction at right angles to the watershed or supposed watershed; these are connected by lines carried along the river banks. The country being thus covered with a network of levels all reduced to the same datum line, and marked down on the map, the general line of *watershed* along which (as has been shown) it is desirable as far as possible to carry our canal, will, at once be evident. This line cutting the cross sections nearly at right angles, should then be carefully levelled as a trial line, as well as any other alternative line that may present itself, and on this the general project will be based.

276. The following hints, drawn up by Major Crofton, R.E., for the Punjab Irrigation Department, on taking levels for a canal project, and on subsequently laying out the line, will be found useful:—

Trial Levelling and Surveying.—In addition to the levels of the country surface, a rough survey or reconnoissance is required, which should give information on the following points, viz.:—Approximate sites of villages or towns, lines of drainage, roads, railways, old water-courses, canal channels (main or rajbuhas), edges of high ("bangur") land, remarkable buildings, wells, nature of soils, crops, trees, &c., position of stone or kunkur quarries, &c.

The places between which roads run, and their bearings (if regularly lined out), should be noted; if on embankment, the level of the top surface should be taken.

The bearings of regularly lined out canal channels or irrigation cuts, and the levels of their beds at points of crossing, with cross sections at right angles to the direction of each, showing level of full supply, are required.

The level of the lowest point in the beds of nullahs where crossed; with sections at right angles to their courses, showing level of highest known flood, and date of its occurrence if ascertainable; the level of surface of water in rivers (noting date of observation); depth of water on lowest point of bed (if obtainable), and level of ordinary and highest known flood; levels of floors of tanks and lowest points of large jheels should be observed and connected with the line of levels. The sites of such sections taken off the line should invariably be connected with the traverse.

The water-way of all bridges or culverts met with on or near the line of level should be measured; and the levels of their floors or plinths of abutments, or the bed under the arches if there be no flooring, with highest flood mark, carefully noted.

Wherever a well is met with or used as a bench-mark, the level of the surface of the water should be noted; the depth below the bench-mark can be measured with sufficient accuracy by the chain. If water is being drawn from the well, the surface will in general be abnormally low, in which case the height at which it usually stands when not in use should if possible be ascertained. The quality of the water, whether sweet or brackish, should also be noted.

These observations of the surface level of the springs should never be omitted, when opportunity offers; it is a point of considerable importance.

The color and description of the soils, whether sandy, clayey, &c.; the presence of the white or brown efflorescence known as "reh" or "kullur" should be noted.

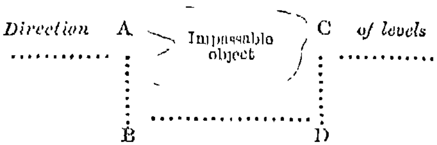
A complete delineation of the drainage lines of the country being one of the primary objects of the survey, too great care cannot be taken in ascertaining their positions. They may be divided (excluding the large rivers) into two classes; the first easily recognizable by their size; well defined channels running in valleys at some depth below the general level of the country adjoining. Into these and the rivers, innumerable channels of the second class discharge themselves, the exact positions of which are not always to be detected by the level alone. They usually rise in jheels lying close to the water-shed, and their courses are marked by a series of jheels connected by intermediate low lands; a black, clayey soil, "reh," rank grass, and crops requiring frequent irrigation, such as sugar-cane, cotton, &c., generally mark the places where water has lain or over which it flows in considerable quantity. No land of this description should be passed over without enquiry as to whether it is flooded during rain, and from what direction the water comes and whither it runs off. "Reh," if contained in the soil, always rises to the surface where water has lain for any time, and appears in greatest quantity during the cold season.

Large towns or villages will almost invariably be found situated close to lines of drainage, or low ground where water collects after rain.

Sand hills, or very sandy soil, generally mark a water-shed on the "bangur."

Where a nullah or drainage line is crossed, and the level of the lowest point of the bed is observed, great care should be taken to ascertain whether this point is on the general level of the bed; if otherwise, the difference above or below should be measured and noted.

Where an impassable object lies directly in the line of direction of the levels, it should be passed thus:—



that is, wherever it is necessary to diverge for a short distance from the given line, it should be rejoined as soon as the obstacle is passed. In plotting the *section*, the points A and B, and C and D should appear identical.

Bench-marks should be established at intervals of about 3 miles in *general*, and one close to every large nullah or line of drainage, as well as at the ends of each cross section or line of levels Existing buildings to be preferred for the purpose.

All Canal, Road, Railway, Great Trigonometrical Survey, or other bench-marks met with *en route*, should be connected with the line of levels.

The error or difference in any circle of levels ought not to exceed one foot per hundred miles traversed. *Small* errors arising from incorrect reading of the staff, not holding it vertically, high wind, and such like are inseparable from all levelling, but these will not be found to *accumulate* if the work be carefully done. Attendency, however, has long been observed, though as yet unaccounted for, to a small cumulative error in the direction of the levels; but this is not found to affect practical operations materially. Where great accuracy is required, such as in the proof levels of a canal channel, it is advisable to level twice over the same stations with the same instrument, the second level being carried in the reverse direction to the first; the mean reduced level of each station will be as nearly accurate as it is possible to obtain it.

For the purpose of determining water-sheds on or near to which it is an object to carry irrigating channels in a generally level country such as we have to deal with, cross sections at intervals, perpendicular to the supposed water-shed, or line running centrically between the drainage lines on either side of the water-shed, will be found most advantageous in economizing time and labor. No rule can be laid down for the distance between any two successive cross sections; it must be regulated by the features of the country. For the general alignment of the main channels between two large rivers, the interval should not exceed 10 miles. For the actual lining out, and for the minor channels, the interval probably should not exceed five miles, or possibly less; though in most cases, I believe, it will be found to answer the purpose better to map out the drainage of the country minutely than to take cross sections at smaller intervals than five miles.

Cross sections should be connected by longitudinal lines between their extremities to test the accuracy of the work; the latter, unless intended for some other special purpose, may be carried on the most direct lines between the points to be connected.

Wherever drainages are met with, enquiries should be made as to their courses both above and below the line of levels, names of villages near which they pass, &c; by thus observing them in each successive line of cross section, a very complete plan of the drainage of the country is obtainable, as well as a connected series of levels along the beds of the outfalls.

Similar information to that detailed above should be obtained with all levelling or surveying for rajbuhas, drainage projects, or any other work connected with irrigation.

In levelling for the longitudinal section of a river, the line should follow generally the main water channel, the stations being invariably on the bank or dry ground near the edge of the stream. The level of the surface of the water at intervals (noting date), of ordinary floods and highest known flood; the position of top and foot of rapids (if any) and level of surface of water at each point to be noted. The depth of water to be measured in the deepest part of the channel where the surface level has been observed. *Cross sections at right angles to the direction of the river* should be taken at intervals and connected with the series of levels, showing the bed, surface of water level of ordinary and highest known flood. The survey should show all minor channels and affluents (if any), and as nearly as possible the extent of land under water in high floods. The nature of the bed, whether of boulders, sand, clay, &c., should be carefully noted.

A prismatic compass held in the hand will be found very useful in filling in details off the line of the series of levels. If the variation of the needle is not identical with that of the level employed, the bearings should be reduced before entering in the field book to the meridian of the latter. Most of the side measurements, where great accuracy is not required, may be made by pacing. Two and a half or three feet paces will be found most convenient as admitting of easy reduction to feet.

The scale generally for protraction of levels should be 1 mile to 1 inch. For the sections, the horizontal scale same as for the protraction; the vertical, 100 times the horizontal. *Larger or smaller scales may be necessary for special purposes; but always* measures or aliquot parts of the one-mile-to-the-inch scale.

On every protraction of levels, besides the heading, the following must never be omitted. Date of the survey, name of the surveyor, scale and meridian line; the numbers attached to the several stations on the section to be identical with those on the protraction.

All details noted in the field-book should be transferred to the protraction or sections; *a sketch and a short description of each bench-mark to be entered on the back* or margin of the sheet in which its position is shown. The information is thus more accessible than if old field-books have to be searched for it.

If a map is to be compiled from levels or surveys taken with more than one instrument, it will be found best to protract the work done with each instrument on separate sheets, to be subsequently transferred on to the map.

Survey and lining out Canal Channels.—Preliminary Survey.—After the position of the line, which may generally be assumed as the watershed, has been approximately determined by means of the cross sections, or otherwise, an accurate traverse with the theodolite should be taken over it, including a survey of the ground for about half a mile in general, or further, if deemed necesssary, on each side, which should give information on the following points, viz. : features of the country, if irregular; nullahs, lines of drainage and jheels wherever met with; sand hills or ridges; towns and villages, wells, buildings, whether of masonry or mud; roads, whether regularly lined out or merely cart tracks—if the former, the bearings should be taken; places between which they run (whether tracks or made roads), and whether they are lines of traffic or merely village communications, should be carefully ascertained (this is useful afterwards in determining the sites of bridges); village boundaries, &c.; such minutiæ as the boundaries of fields are unnecessary; those of gardens may be useful; in fact, everything which is likely to be of assistance in determining the precise line, or which it would be advisable to avoid if possible. A survey of this nature, carefully taken, will generally admit of choosing a line which will injure property or disturb existing rights in the least possible degree.

The accuracy of the traverse is the point to be chiefly looked to ; the distance between the stations on it should be as long as possible ; never, if practicable, less than a mile, as the probabilities of accuracy in observation are greater in the case of long than short sights, and the plotting is easier as well as more likely to be accurate. The sights to the station poles should be taken as in ordinary traverse surveying, but should show the magnetic bearing of the lines, or their supplements ; these should be checked by repeating the observation at each station, thus :—Clamp the upper plate on zero of the lower and fix on back pole ; then turn upper plate round to sight fore pole, noting the angle in the field-book ; this angle should equal the difference of the magnetic bearings first observed. This will check the directions of the traverse lines. To check the distances between stations :—Fix on a well defined point some distance to one side, say a mile, and observe to it from every station from which it is visible. If the distances have been measured and plotted correctly, and the bearings are accurate, the latter will all meet in one point on the map.

The stations may be marked on the ground by large pegs, about three feet long, driven well in. If their future identification is an object, and there is a chance of the pegs being destroyed or removed, a ghurrah filled with charcoal, buried at some depth below the surface of the ground, will give the means of finding their sites again with sufficient accuracy for all practical purposes. The surest way, however, is to note their distances and bearings from any easily recognized and permanent objects which are not likely to be disturbed, if such should be found sufficiently near for the purpose. It will be found most convenient to fix all stations on mounds or rising ground.

All bearings taken with the theodolite should be noted to the smallest portion of a degree its graduation will admit of ; for, although they cannot be plotted nearer than to a minute, close observations are necessary to ensure accuracy in a long line of survey. Bearings should be taken to all well defined objects, such as spires of temples, &c., wherever visible ; though possibly useless for the special purpose of the survey, they may be of importance hereafter in giving the means of joining on other surveys to any of the traverse stations.

The angles on the side surveys may be taken with a good compass, prismatic, or of any other description available ; the actual bearings, as shown by the instrument employed, being entered in the field-book, *i. e.*, no correction being made *in the field* for the variation of compasses (if any). Villages should be traversed round, so as to determine their outer limits, but no interior survey is required. These should be connected with points on the main line of traverse ; the correctness of the junction line may be tested by observing from several points on it to some object in or near the village (such as a large tree, house, &c.), which has been well connected with the boundary survey of the village.

As the choice of a good line and the actual lining out on the ground very much depends on the accuracy of map, this should be placed beyond a doubt, if possible, before the line is chosen and marked on it. The time occupied in taking check observations and measurements in the field will be well repaid by the facilities afforded to the subsequent work by a really accurate plan of the country.

It will be found convenient to have two descriptions of poles (jhundees) for setting up on stations to which observations are to be taken, one for use in windy weather, mounted with a flag; the other when the air is calm, with a small "moon" (made by covering a wooden hoop with calico), about 1½ feet diameter; as a flag when not flying free is scarcely more distinguishable at a distance than the bare pole. On the revenue survey, poles painted in foot lengths, white and black alternately, are employed, which makes them visible at a far greater distance than the common uncolored bamboos.

The position of the actual water-shed near the line of traverse should be carefully ascertained and noted on the map.

Lining out.—If the levels of the water-shed admit, the nearer the line of canal approximates to it the better: the interference with the surface drainage of the country being then the least possible. It should be laid down in straight lines as far as practicable; the fewer the curves the better; none, unless in special cases, of less radius than three miles or 15,000 feet, though curves of 5,000 feet radius on the Baree Doab Canal have been found to answer very well. It is of course a desideratum to avoid villages, buildings, and valuable property of all kinds if possible, and this can generally be effected without sacrificing the primary considerations which should guide the choice of a line, if the map be accurate and give sufficient detail.

Wherever the water-shed cannot be adhered to exactly, ground should be chosen from which the surface drainage can either be passed into the canal channel or turned off in some other direction; otherwise jheels and swamps will form after rain on its water-shed bank. It should be considered, however a standing rule, that no drainage water should enter the canal channels, large or small, unless it be *impossible* to dispose of it in any other way.

The centre line of the intended channel having been laid down on the map, and from it transferred to the ground, all boundaries, &c., can subsequently be demarcated from it. In laying down curves on the map, the use of "French curves," or card board cut to the required shape, will be found to facilitate the process considerably.

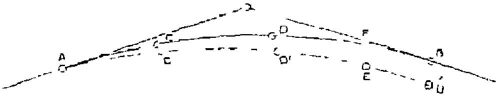
The following is recommended as the least laborious method in the description of country with which we have to deal, of transferring the line on to the ground, and is sufficiently accurate for all practical purposes.

First, for the straight portions. Find the approximate bearing of the line and measure offsets to it from two survey stations, say two or three miles apart, on the map. These offsets measure off on the ground; two points are thus obtained in the required line, which may then be produced either way at pleasure.

Where a curve is required, produce the tangents (obtained as above) on the ground till they meet, marking their intersection as described for survey stations; the angle between them may then be observed, and their lengths found by calculation for a curve of the radius previously determined on the map. Measure off these lengths from the intersection, marking the commencement and end of the curve thus obtained by large pegs. In cases where the intersection falls on ground from which the lines of tangents are not visible, the angle between them must be obtained from the map, and the lengths calculated therefrom. The points marking the termini of the curve being thus determined on the plan, they must be transferred to the ground lines by measurement from some points fixed by the survey.

In laying down the curve itself, it will be sufficient for all practical purposes to fix points at such intervals that the versed sine of the intercepted arc should not exceed 0·25 foot, or thereabout. Those points may be obtained by offsets from the tangents where the maximum length of such offsets does not exceed 30 to 35 feet; above this limit, it will be advisable to adopt the method of offsets from chords. Calculate the number of chords of a constant length (1000 feet or 2000 feet answer best in practice), and the length of the remaining chord contained in the curve. Proceed to lay them down in the usual way with theodolite and chain commencing from one end of the tangent; if correctly done, the end of the last chord wall fall on the peg marking the termination of the other tangent.

If there is some small difference on closing (and in a long curve this generally occurs in direction; seldom in length), correct thus—

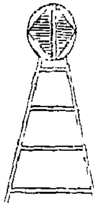


Supposing A C′ D′ E′ B′ to be the line as laid down on first trial, and A C D E B the correct one; the distance B B′ being measured, the corrections for the other chord ends or distances E E′, D D′, C C′, may be found by assuming the space between the two curves to be a triangle, and the lines, E E′, &c., to be drawn parallel to the base B B′; B B′ and the lengths of the chords and the entire curve being known, the corrections are easily obtained; then returning over the curve, correct the positions of the pegs marking chord ends. If the difference in the *length* of the curve is considerable, it will be advisable to go over the work altogether again; this, however, with careful work seldom happens.

Having thus fixed the ends of the chords, lay off the offsets distant from each other not more than 200 feet, if on a curve of three miles radius or upwards; on curves of less radius the interval should not exceed 100 feet. These points may be marked by pegs about 1½ foot long.

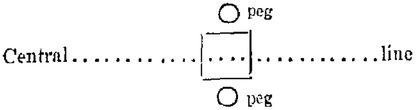
Chords of 2000 feet in length will answer for curves of 3 miles radius and upwards, for radii of 2 miles and 1 mile, 1000 feet chords.

In laying down long straight lines it will be found advisable, and in very uneven ground absolutely necessary, to use one or two signals of much greater height than the ordinary flag staff. Such a signal may be made, as shown in the annexed sketch, by connecting two bamboos, say 40 to 50 feet long, in the form of a ladder, joined at top, and about 5 feet apart at bottom, by cross pieces at intervals; a "moon," formed with a wooden hoop strengthened with cross pieces and covered with calico, being fastened at top; the centre of this moon is then adjusted over the line by a plummet, and the whole is secured in its position by three guy ropes attached to large pegs.



Other methods of laying down curves may be necessary where the ground is much encumbered with obstacles; but for the description of country usually met with in the plains of Northern India, the method above described will, it is believed be found the simplest and most practical.

The ends of curves should be marked by a small cube of masonry sunk to the level of the ground, as it is difficult afterwards to find the exact positions, if some permanent mark be not made at the time of lining out. Bench-marks of masonry (one foot cube will answer) should be sunk to the level of the ground at intervals of 500 feet along the central line of canal, and numbered on top to denote the distance from the zero of longitudinal measurement. Those denoting even thousands of feet to be marked with integers; the intermediate ones thus, "$\frac{1}{2}$." It will be found a great saving of time if the positions of these bench-marks be marked simultaneously with the lining out, and this may be done by driving in two pegs thus:—



Position of B. M.

On straight lines one chain only is necessary; on curves two should be employed; one in measuring distances along the chords, or tangents (as the case may be), for the offsets, the other meanwhile following along the curve. By this means the nick can be cut and the bench-marks laid in immediately in the wake of the surveyor; and the sooner this can be done the better, for none but marks of masonry will long remain where people and cattle are constantly going to and fro. The bench-marks, however, should not be waited for to commence cutting the nick; this should be dug at once about half a foot deep; a long narrow cut is not easily effaced. The marking out and cutting the boundary nicks should follow that of the central line. If there is any fear of the bench-marks being injured by cattle, &c., cover them with a small mud pillar.

The chain for measuring distances along the central line should be exactly 100 feet long, and its length should be constantly checked, as this measurement must be as accurate as it is possible to make it.

The zero of longitudinal measurement for the central channel of a canal is the face of the up-stream head wall of the regulating bridge at the head. For the branches, or any minor channels, the same line on their respective regulating bridge heads.

The details of all curves, such as the angles between the tangents, length of tangents, number and length of chords, &c., reduced distances from zero of longitudinal measurement, of extremities of curves, crossing points of roads, nullahs, &c., and all other items of information likely to be useful hereafter in the construction of the works, should be noted in the field book *on the spot.*

In aligning the minor irrigation channels, so great accuracy is unnecessary, as curves may be more frequent and of smaller radius; but the same care should be taken as in the case of the larger channels, to avoid as far as possible injury to existing property or disturbance of existing rights.

For producing straight lines on the ground, a theodolite is unnecessary; a good reconnoitring telescope will be found to answer the purpose perfectly.

277. In the actual construction of the line the *Cuttings* will be laid out and made like road cuttings, but it is evident that the *Embankments* must be different, as they have to retain within them a large body of water. Their thickness must, therefore, be very great on both sides of the water channel, and they vary in mean width from 30 to 100 feet, according to

the depth of water. If leakage occurs they must have a wall of puddle, or be otherwise rendered water-tight.

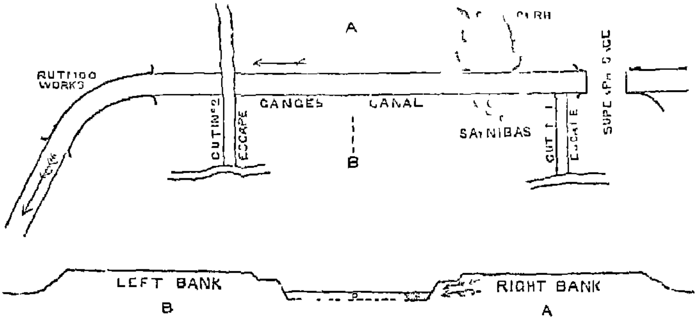
The method of constructing the cuttings and embankments has been sufficiently treated of in the Section EARTHWORK.

278. In the annexed Plate are some cross sections of the Ganges Canal taken at different points along its course, showing the channel as originally excavated, and the following account of the method of excavating the most difficult portion of the line will be found interesting

From the Puttri Super-passage to the Rutmoo River—This is perhaps the most interesting line of work that has been excavated The length is equal to 16,810 feet. On its course it passes through a ridge upon which the villages Gurh and Saynibas are situated, and with the exception of the super-soil, to a depth of from 7½ to 20 feet, it is entirely excavated through earth impregnated with springs

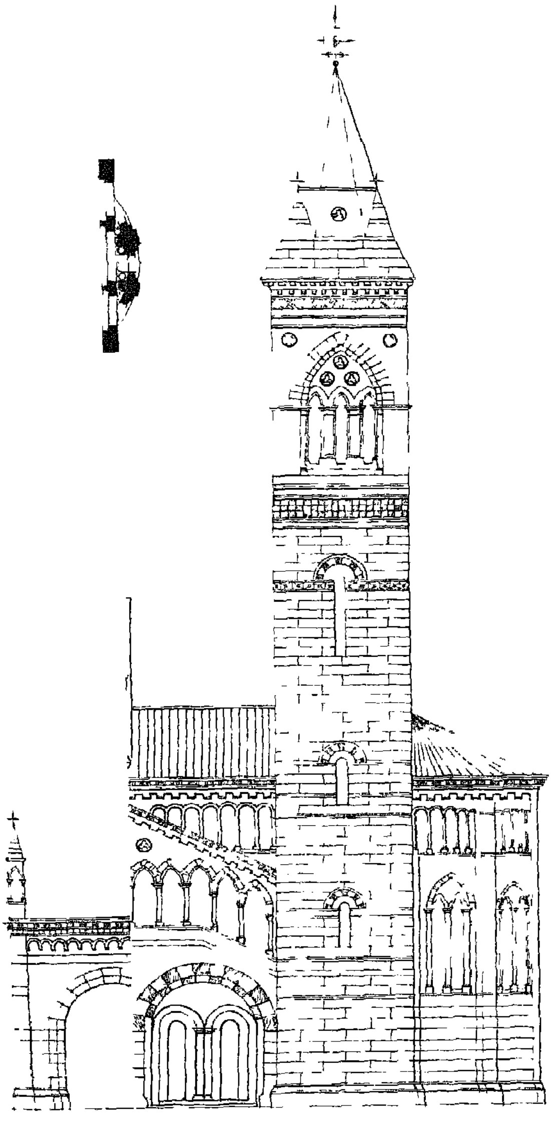
The work was tedious and very expensive; it required, moreover, the constant vigilance of an active supervisor, to see that what was done in one day, was not by the action of the springs undone the next The spring-water, which is kept down by impervious superstrata, rises immediately it escapes from its bondage At a nulla which is intersected by the canal, water runs in a perennial stream The difficulty of excavating this portion of the canal, may be comprehended by explaining that the stream in question, naturally runs on a level of 8·18 feet above that of the canal bed. This nulla was merely an external exhibition of the spring level throughout the whole line of country now referred to

After removing the super-soil, or that unconnected with springs, an escape was made near the above nulla The distance from the Puttri to this nulla is 10,[illegible]04 f so that, in making use of the escape, for the relief of spring-water during the excavations, a considerable slope was available. The direction of the spring current is



from north to south, or from the high to the low land The canal channel intersects this at right angles. The Executive Engineer's plan of operations will be best understood by diagrams showing the line in plan and section.

VARSHA



The true section of the canal in its full depth is represented by the dots. The way that this was reached will be understood by the shade C, Fig. 2, which represents a ditch or cunette, in this case a catch-drain for the spring-water which flowed in the direction of the arrows. This cunette was carried along the whole line of excavation, and terminated in the escape No. 2. Both cunette and escape were maintained in a constant state of efficiency as regards the free run of water. By the interposition of cunette C, that portion of the canal channel at D, Fig. 2, was excavated without trouble, as it was entirely cut off from its spring supply. The process was a very gradual one. As the depth of the cunette was increased, so did the portion D become relieved of its difficulties. It was an operation requiring especial care; and in a pecuniary point of view, the greatest attention to prevent the work of one day being obliterated by the action of springs during the night-time. The whole work was however completed, satisfactorily.

279. The considerations which determine the site of the canal head have already been noticed. The canal should be made to *tail* into a river or nullah, into which the surplus water unexpended will be discharged, and in order to secure an efficient scour, it will be advisable slightly to increase the velocity at the end. A fall into the outfall nullah or river is generally the best way of effecting this.

280. The points at which *Branches* should be taken off from the main line as well as the general course of these branches will be fixed from a due consideration of the levels of the country and the extent of culturable land requiring irrigation. If the main canal has been carried on or close to the watershed or backbone of the district, then the branches should be lined out as far as possible on the minor ridges which lie on both sides of the main ridge, the object in every case being to keep a sufficient command of level for surface irrigation. There is a further reason for carrying the canal channels on watersheds wherever possible, viz., to ensure the minimum of interference with the country drainage, the importance of which will be explained further on, and to ensure an efficient scour at the tail of the channel. The size of the branch channels and slope of their beds will be dependent on the same principles as those already noted in the case of the main line, and the same remark applies to the *Rajbuhas* or distributing water-courses which are led off from the main and branch lines, and from which it is now the most approved practice to deliver the water for the actual irrigation, its further employment being left to the cultivators.

281. *Bridges* of communication are required wherever roads cross the canal, and for the general convenience of the country. On the Ganges Canal they were designed at about every three miles; and, when in the vicinity of large villages, are provided with *ghâts* or steps for convenience of bathing. Care should be taken to provide sufficient headway under the arches or openings for laden boats to pass easily when the canal has its full supply. On the Soane Canals 13 feet are allowed for this purpose, and it is also desirable that the obstruction to the stream presented by the piers should be as small as possible; for this purpose it will generally be advisable to widen the canal slightly at these points so as to allow a *full* waterway for the stream through the bridge. Otherwise, expensive precautions have to be taken to secure the foundations, and the increased velocity under the arches will render navigation dangerous or at least difficult.

282. A *Tow-path* should be provided on at least one side of the canal at a constant level of 1 to 2 feet above the water surface. It may be from 12 to 15 feet wide in earthen section, and not less than 6 feet under bridges, the tow-paths should be carried *under* the side arches, of bridges, in no case through the abutments or wing walls, the latter arrangement being an obstacle to free navigation.

283. A *Road* is also desirable on one side of the canal for convenience of inspection. It may be 20 feet wide and planted with trees. Tree *plantations* are also general along the canals of the N. W. Provinces. No trees should, however, be allowed within 30 feet of the water's edge, as their proximity interferes with the stability of the embankments.

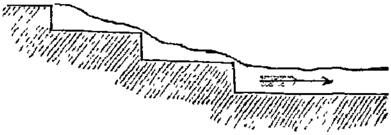
284. *Chokees* or stations for the Engineers and Overseers employed on the line are also provided at intervals, and are generally fixed at the sites of the most important masonry works.

These works, which are required for the admission, control and distribution of the water, or for the passage of the canal across the drainage of the country, will now be described.

CHAPTER XLIX.

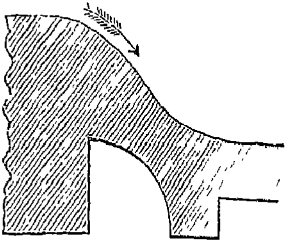
FALLS—RAPIDS—LOCKS.

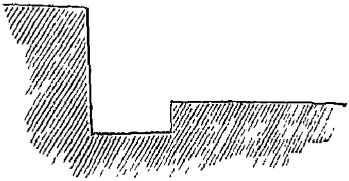
285. So long as the slope which we determine to give to the bed of our canal from the considerations above stated, is the same as the natural fall of the country through which the canal is excavated, the level of its bed will of course remain at a uniform depth below the surface of the ground. But although this can generally be managed in the flat plains of these Doabs throughout the greater portion of their length, yet in the *upper* portion of the canal, the slope of the ground is very much greater than that which it would be proper to give to the canal bed, and peculiar arrangements have to be made to compensate for this difference of slope. The annexed diagram will show how this excess of fall has to be overcome; viz., by laying out the canal bed in a series of *steps*, so as to keep it at a tolerably uniform level below the surface of the country, until the flat country is reached where the slope is the same as that proper for the canal.



The points where the bed is let down from a higher to a lower step are called *Falls ;* and their shape and construction are questions requiring much thought and consideration. Their location should evidently, from the diagram, be near the places where the canal bed, if continued without a break, would have to be carried in embankment above the surface of the country; their *exact* position is generally made to coincide with the requirements of a bridge or some other masonry work such as are described hereafter, for the sake of economy of construction, or on other grounds which need not be entered upon here.

It is evident that the fall must be of some more durable material than earth to resist the action of the water over the step, and masonry is therefore employed The bed of the canal has also to be protected by a masonry flooring from the plunging action of the water, and the banks must also be revetted for a considerable distance below to prevent them being cut away. The exact shape of the fall itself is a point on which there is much difference of opinion. Ogee falls of this shape were employed by Sir P. Cautley, on the Ganges Canal, with the idea of delivering the water at the foot of the fall as quietly as possible. On the Baree Doab Canal vertical falls are used, the water being received at the bottom into a cistern sunk below the level of the flooring, which thus forms an elastic cushion, as it were, to receive the shock instead of opposing a dead resistance to its force; while the accelerated velocity of the falling water in a forward direction is thus also checked. The action of the water is still further lessened by making it play over a wooden grating, by which it is divided into a number of filaments or threads, as if it were discharged through the teeth of a comb.

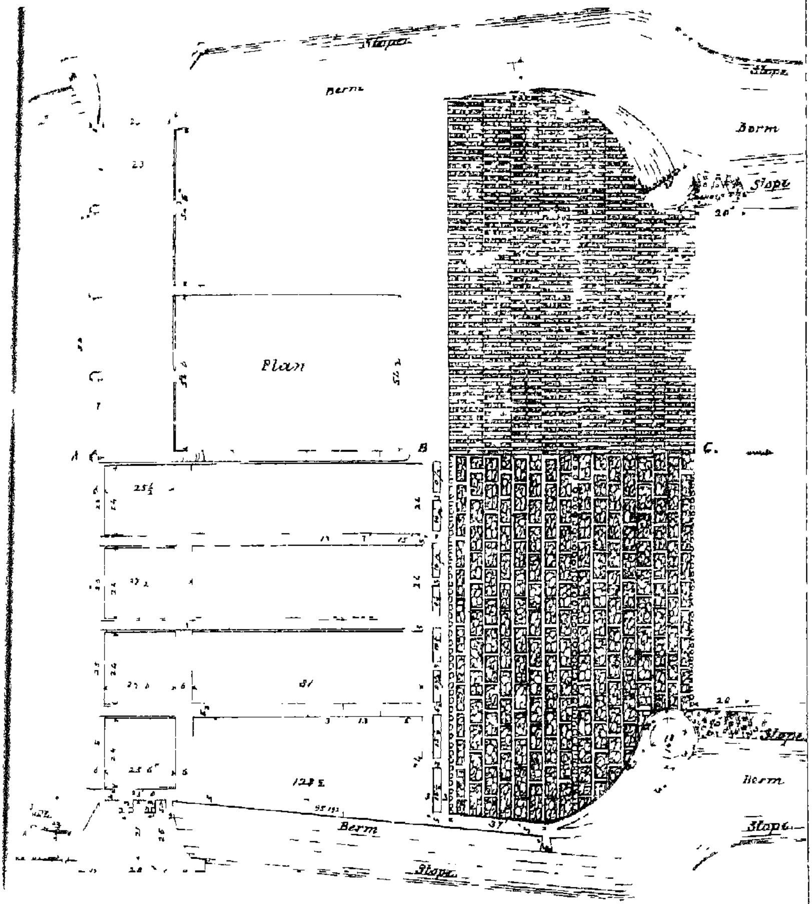




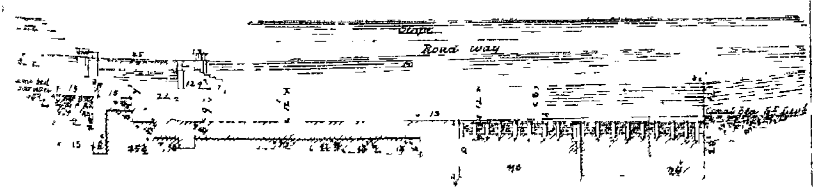
286. The very dangerous scouring and cutting action of a large body of water falling over a height of even a few feet, must be seen to be fully appreciated. The greater the height of the falls and the depth of water, the more violent of course will be the action; those on the Ganges Canal are not higher than 8 feet, but with 6 feet or more of water going over, the action is most severe, and nothing but the very best masonry is capable of resisting it. If stone can be obtained, it should always be used; if not, none but the hardest bricks must be employed, laid on an unyielding foundation with fine mortar joints; the banks must be revetted with masonry for a considerable distance down-stream, and the bed of the canal protected by a solid masonry flooring, the tail of which is defended by a row of sheet piling. The fall should be divided into distinct chambers which can be laid dry one by one for the sake of repairs without stopping the canal. On the Ganges Canal the masonry flooring is continued to the end of the chamber, beyond which, crib-work of dry boulders is employed as far as the end of the revetment walls.

PLATE LV

OGEE FALLS—GANGES CANAL



Section on A B C



The revetment walls on this canal were inclined slightly inwards and terminated by curved walls (*see* Plate), with a view of holding up the water on the flooring, and thus saving the latter from the effects of any scour. But the result has been, serious cutting of the banks below the curved ends, and the curved walls are now being removed in consequence. On the Belra Falls on this canal, the revetment walls were carried straight on instead of being inclined inwards, and then terminated by curves forming a basin; and these have answered better, though it is said the soil is there much stronger.

287. The following is a description of one of the Ogee* falls on the Ganges Canal, drawings of which are given in the Plate:—

The fall consists of a bridge (of eight bays of 25 feet in width each), which crosses the canal on the upper levels; to the tail of this bridge the ogees are attached, delivering the water into four chambers of 54½ feet each in width, every alternate bridge-pier being prolonged on its down-stream face, so as to divide the space which is occupied by the lower floorings into four compartments; in advance of the three dividing walls, which are carried to a distance of 84 feet from the down-stream face of the bridge, there is an open space of masonry flooring, which is protected by an advanced area of box-work, or heavy material filled into boxes or crates, and covered with sleepers, so as to retain the material in position. Additional defences are given to these floorings by lines of sheet piling. The flanks of the chambers below the descent are protected by revetments,

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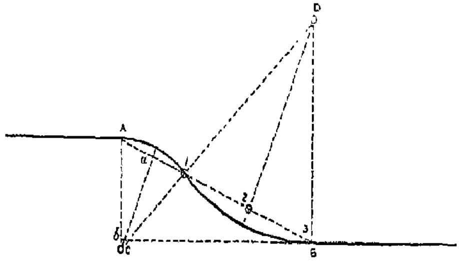
* The curve of the Ogee is thus described:—



$b B = \frac{5 A b}{2}$

$A 1 = \frac{A B}{3}$

A C } Perpendicular
D B } to Flooring.

Bisect A 1, and from the point of bisection at *a* draw a perpendicular cutting the line A C at C.

Join C 1, prolonging the line until it cuts the line D B at D.

From the points C and D as centres draw the curves of the oges.

equal in height to the dividing walls These flanks, instead of being in prolongation of the alignment of the bridge abutments, expand outwardly, gaining, on their arrival at the tail of the masonry platform, an excess of 20 feet in width. At a distance of 37½ feet from this point, the flanks make a slight curve inwards, terminating (on an imaginary line drawn in prolongation of the pier next to the abutment) in massive projecting jetties. Between, and on the flanks of these two jetties, lines of piles, and other protective arrangements are distributed, so as to secure the safe passage of the water over the floorings, and to admit of the current escaping from the works with as little tendency to danger as possible. The depth to which the curtain or upper foundation wall is carried is equal to 20 feet; that of the tail, with the flank revetments and jetties, is also 20 feet

288. The result of experience seems to show that the vertical falls with gratings as used on the Baree Doab Canal, are the best that have yet been invented. Their construction will be understood by the inspection of the Plate, and the following Memo. refers to the arrangement of the grating—

The grating consists of a number of wooden bars resting on an iron shoe built into the crest of the fall, and on one or more cross beams, according to the length of the bars. These bars are laid at a slope of 1 in 3, and are of such length that the full supply level of the water in the canal tops their upper ends by half a foot. The scantling of the bars as well as that of the beams should of course be proportioned to the weight they have to bear, plus the extra accidental strains to which they are liable, from floating timber for instance, which may possibly pass between the piers and so come in contact with the grating. In consideration of strains and shocks of this nature the supporting beams are set with their line of depth at right angles to the bars instead of vertically.

The dimensions of the bars used on falls of the Baree Doab Canal, where the depth of water is 6·6 feet, are as follows:—

Deodar wood.

Lower end of bars, 0′·50 broad × 0′·75 deep,
Upper end of bars, 0′·25 broad × 0′·75 deep,

and they are supported on two deodar beams, each measuring 1 foot in breadth × 1·5 foot in depth; the first beam being placed at a distance of 7·5 feet (horizontal measurement) from the crest of the fall, and the second 7·5 feet beyond the first beam. The bars of the grating on these Falls were originally placed touching each other (side by side) at their

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lower ends, as there was not then a full supply of water in the canal. There were thus 20 bars in each 10-foot bay. Since then the number of bars has been successively reduced to 19 and to 18, the present number. The reduction of the number of bars and the equal spacing of the remaining bars is done with ease, as they can be pushed sideways in the iron shoe and along the beams, to which latter they are held with spike-nails. Once the correct spacing is arrived at, cleats and blocks (as shown in the drawing) are preferable to spike-nails.

The end elevation of the bars, shows the way in which the bars are undercut from the point where they leave the shoe, *i. e.*, from the crest of the fall. This undercutting has the effect of making each space as it were "an orifice in a thin plate," and it facilitates the escape of small matters which may be brought down with the current. Large rubbish which accumulates on the grating is daily raked off and piled on one side of the fall. This is done by the establishment kept up for the neighbouring lock. There is considerable advantage in thus clearing the canal of rubbish which would otherwise stick in rajbuha heads, on piers of bridges, &c., or eventually ground on the bed of the canal and become nuclei of large lumps and silt banks.

289. The effect of a fall occurring at the end of a canal reach, is to increase the velocity, and diminish the depth of the water for a considerable distance above the fall. This increase and diminution are gradual from the point where this action commences (rather an uncertain question), down to the fall itself where, of course, they attain a maximum, so that the depth of water passing over the fall is very much less, as the velocity is very much greater, than the normal depth and velocity above. This increase of velocity before the water reaches the fall, produces a dangerous scour on the bed and banks of the canal, and in order to guard against this, it has been found necessary to head up the water at the falls on the Ganges Canal by means of sleepers dropped in the grooves of the piers, which has virtually increased the height of the fall, and has been one cause of the flooring suffering in places from the violent action of the water. It has also been proposed to narrow the falls so as to produce the same effect.

290. The method most commonly adopted, however, is to raise the crest of the falls by a masonry weir; and the height to which it is necessary to raise the weir, may be found from the following calculation, as given by Colonel Dyas.

Discharge over Fall (complete) $= ml\left(h + \frac{v^2}{2g}\right)^{\frac{3}{2}} = ml\left(h + \frac{n^2d}{2gs}\right)^{\frac{3}{2}}$ and discharge in an open channel $= \mathrm{A}\,n\left(\frac{d}{s}\right)^{\frac{1}{2}}$

In which equations—

A = Sectional area of open channel.

d = Hydraulic mean depth of same.

s = Length of slope to fall of one in same.

v = Mean velocity of current in same.

h = Height of surface of water in same, above crest of fall.

l = Length of crest of fall.

m = A co-efficient determined by experiment varying from 2·5 to 3·5

n = A co-efficient determined by experiments varying from 75 to 95.

The discharge in the open channel and that over the Fall are identical, hence we have—

$$m\,l\left(h + \frac{n^2d}{2gs}\right)^{\frac{3}{2}} = \mathrm{A}\,n\left(\frac{d}{s}\right)^{\frac{1}{2}}$$

from which we get—

$$l = \frac{1}{m}\,\frac{2\,\mathrm{A}gns\,\sqrt{2dg\,(2ghs + n^2d)}}{(2ghs + n^2d)^2}$$

and if we put $g = 32{\cdot}19083$, $m = 3$, and $n = 90$, we shall have

$$l = \frac{{\cdot}0213\dot{3}\,\mathrm{A}s\,\sqrt{d\,({\cdot}008hs + d)}}{({\cdot}008hs + d)^2}$$

$$h = \left(\frac{\mathrm{A}^2dn^2}{m^2l^2s}\right)^{\frac{1}{3}} - \frac{dn^2}{2gs} \text{ and}$$

if g, m, and n, are as before

$$h = \left(\frac{900\,\mathrm{A}^2d}{l^2s}\right)^{\frac{1}{3}} - 125{\cdot}8122\,\frac{d}{s}.$$

Having thus got the value of h, deduct it from the depth of water in the channel, and we have the height to which the weir should be raised above the true bed of the canal.

291. Where gratings are used, these act instead of a weir in checking the velocity of the water above the falls, and the following refers to their employment in this manner.

As one main object of the grating is to prevent the stream above the fall to which it is fixed from knowing that there is such a thing as a fall anywhere below it, the principle to go on in spacing the bars is to arrange them so that the velocity of no one thread of the stream shall be either accelerated or retarded by the proximity of the fall. This effected, it is evident that the surface of the water must remain at its normal slope, parallel to the bed of the canal, until it arrives at the grating. The half foot by which the water tops the bars of the grating, as above described, causes a sudden drop there, but the acceleration to the current resulting from so small a fall as this is not practically felt to any distance back from the fall.

To take an example, let us assume that V (mean velocity) = 0·81 v (surface velocity), and U (bottom velocity) = 0·62 v (surface velocity) in every vertical line of the current flowing naturally. Then, if we make V = 2·5 per feet second, we shall have the following velocities at the given depths below surface in a stream 6 feet deep.

Depths below surface.	Velocities (feet per second).	Remarks.
Surface, ... 0	3·0864	Common difference 0·1955, nearly.
1′	2·8909	
2′	2·6955	
Centre, ... 3′	2·5000	
4′	2·3046	
5′	2·1091	
Bottom, ... 6′	1·9136	

What is required, then, is to shape the sides of a given number of bars placed in a given width of bay, so that the above velocities may be maintained till the water touches the grating, when in consequence of the clear fall the velocity becomes considerably accelerated. This accelerated velocity multiplied by the reduced area (of space between the bars) should give the same discharge, with the canal running full, as the product of the original normal velocity and the original undiminished space, the width of which is, of course, the distance between the centres of two contiguous bars.

Thus, taking the lowest film (along the bed of the canal) whose normal velocity is 1·9136 foot per second, and supposing 20 to be the number of bars in each 10-foot bay, then the undiminished space for each portion of the stream will be half a foot, which multiplied by the above velocity gives a product of 0·9568. Again, taking the same lowest film as it passes through the grating, with a clear fall, and under a head of pressure of 6 feet, we find its velocity to be 19·654 feet per second. Now, if we call the required width of space between the bars at this point x_b, and assume the co-efficient of contraction to be 0·6, we shall have $x_a = \frac{0·9568}{19·654 \times 0·6} = 0·08$ foot.

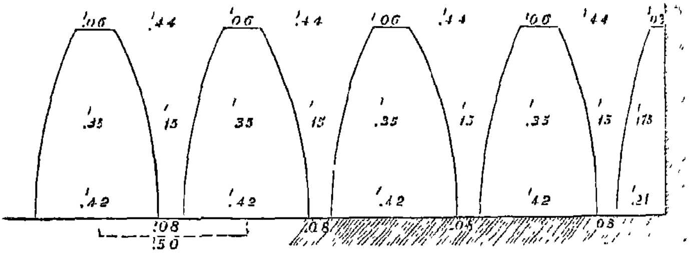
Similarly, taking the film on the level of the tops of the bars, or 0·5 foot below the surface of the water, the normal velocity of which is 2·9857, the undiminished space being as before 0·5 foot, we get a product of 1·4944; and as the velocity of the film falling through the bars is 5·673 feet per second, we get

$$= x_b \frac{1·4944}{5·673 \times 0·6} = 0·44 \text{ foot.}$$

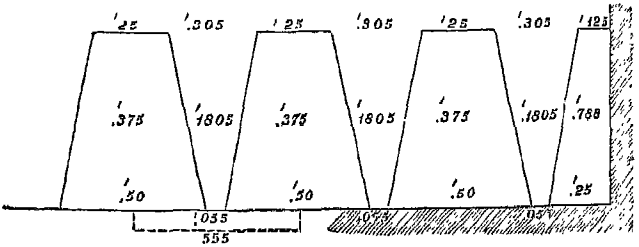
And, lastly, taking the centre film, the normal velocity of which is 2·5 feet per second, we have a product of 1·25, and as the velocity of the same film passing through the grating is 13·89 feet per second, we get

$$= x_c \frac{1·25}{13·89 \times 0·6} = 0·15 \text{ foot.}$$

Hence it is seen that the sides of the bars should be cut to a curve convex towards the open space, but in practice this nicety is scarcely requisite.



The effect of cutting the bars straight is of course to increase the discharge through the centre of the grating, and to diminish it at the surface.



But this is not found objectionable in practice, for, as mentioned above, the surface velocity has already been somewhat accelerated by the half-foot drop at the top of the grating; and, in consequence of the tendency of the lower part of the grating to clog with matter brought down by the current, there is no risk of undue acceleration to the bottom velocity.

The above remarks have been limited to a consideration of the effect caused by the grating on the channel above the fall. Its effect on the channel below the fall is equally important, but this may be gone into separately. For the present it may suffice to remark that the formula in use on the Baree Doab Canal for the depth below the lower bed of the channel is

$$x = \sqrt{h}\ \sqrt[3]{d}$$

in which empirical equation,

x, is the required depth of cistern,

h, the height of fall, or the difference of level between the surface of water above the fall and the surface of the water below it,

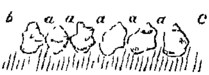
and d, the full supply depth of water in the channel.

All the cisterns with depths thus obtained have answered admirably, having never required the slightest repair since they were built.

202. Instead of falls, and to accomplish the necessary change of level, *Rapids* have been employed with success on the Baree Doab Canal, *i. e.*, the fall is laid out on a long slope (15 to 1) instead of by a single drop; the slope being paved with boulders, laid without cement, and confined by walls of masonry in cement, at intervals of 40 feet both longitudinally and across stream. The longer the slope, the more gentle is, of course, the action of the water; but the greater, also, is the quantity of masonry employed. In general, the choice between the two is a mere question of expense and material available. On the above canal, rapids were adopted wherever boulders were procurable at moderate cost.

Boulders are the proper material for the flooring of a rapid, and brickwork should not be used in contact with currents with such high velocities. Even the very best cannot stand the wear and tear for any length of time, and stone should be used for all surfaces in contact with velocities exceeding (say) 10 feet per second.

The boulders used should be grouted in with good hydraulic mortar and small pebbles or shingle. Dry boulder work is not to be depended on for velocities higher than 15 feet per second, even when they weigh, as much as one maund each, and are laid at a slope of 1 in 15. There should be no attempt made to bring the surface of the boulder work up smooth by filling in the spaces *a a a*. All that is necessary is to lay the boulders and to pack them so that their tops are pretty well in line as *b c*; any further



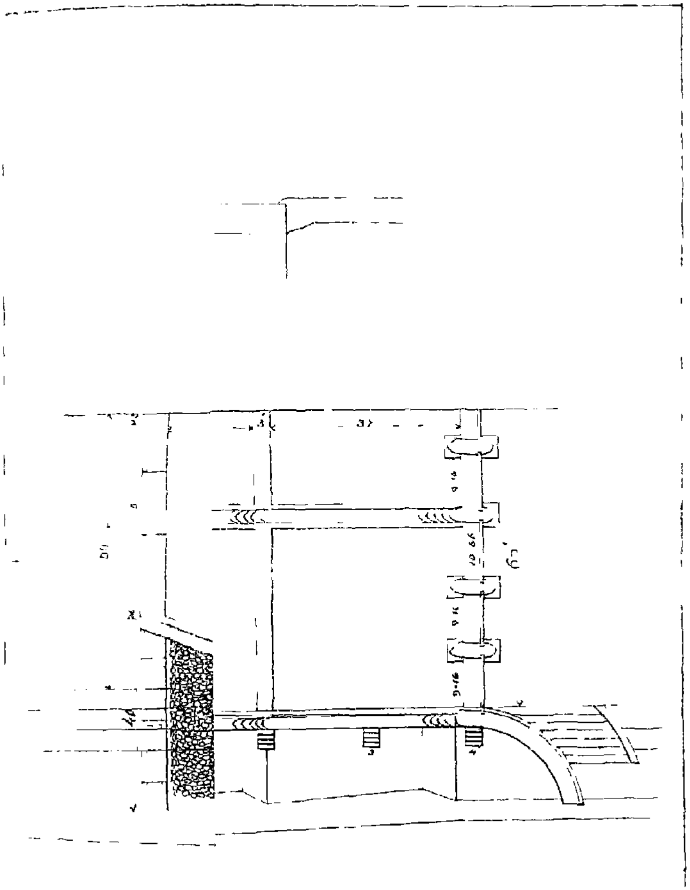
filling in would stand a good chance of being washed out very soon, and, if it remained, its effect would be to increase the velocity of the current on the rapid by diminishing the resistance presented to the water by the rough boulder work.

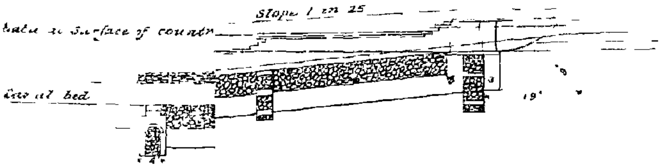
The Baree Doab Canal Rapids have tail walls of peculiar construction for the purpose of destroying back eddies, and of protecting the Canal banks below the rapid from the direct action of the current. These tail walls are intended to be so arranged that the heaviest action of water at the foot of the rapid shall take place in the widest part, and they incline towards each other from this point so as to direct the set of the stream well to the centre of the canal, thus protecting the banks from the direct action of the current for a considerable distance. At the same time, as may be seen from the longitudinal section, the tail walls are not kept at their full height throughout, but beginning (a little below the point where the curve ends) at the level of full supply only, they gradually become lower and lower (slope 1 in 20) till they vanish altogether, where they are on the same level as the bed of the canal. The triangular spaces behind the tail walls in plan are filled in with boulders (dry) to the level of the top of the sloping tail wall; when the full supply is running these tail walls are submerged and invisible, the rapid appearing to end just below the end of the curve.

These tail walls do not check the "lap-lap" or ceaseless wave-like undulation of the water below the rapid, but they effectually do away with back eddies by keeping the current always in onward motion, exposing no abruptly terminating projection behind which an eddy can form, and at the same time they protect the banks by making that motion moderate in the neighbourhood of the banks.

In case no such tail walls are given, the banks should be faced with boulder work, *jamah* or piling, for a length on each side, of say 300 feet below the rapid. Some such protection will always be necessary for the banks.

The maximum velocity of current which a boulder rapid will stand without injury cannot be exactly determined. But experience has proved that a boulder rapid with a flooring composed of boulders not less than





of Tail Counterfort.

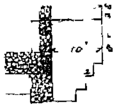
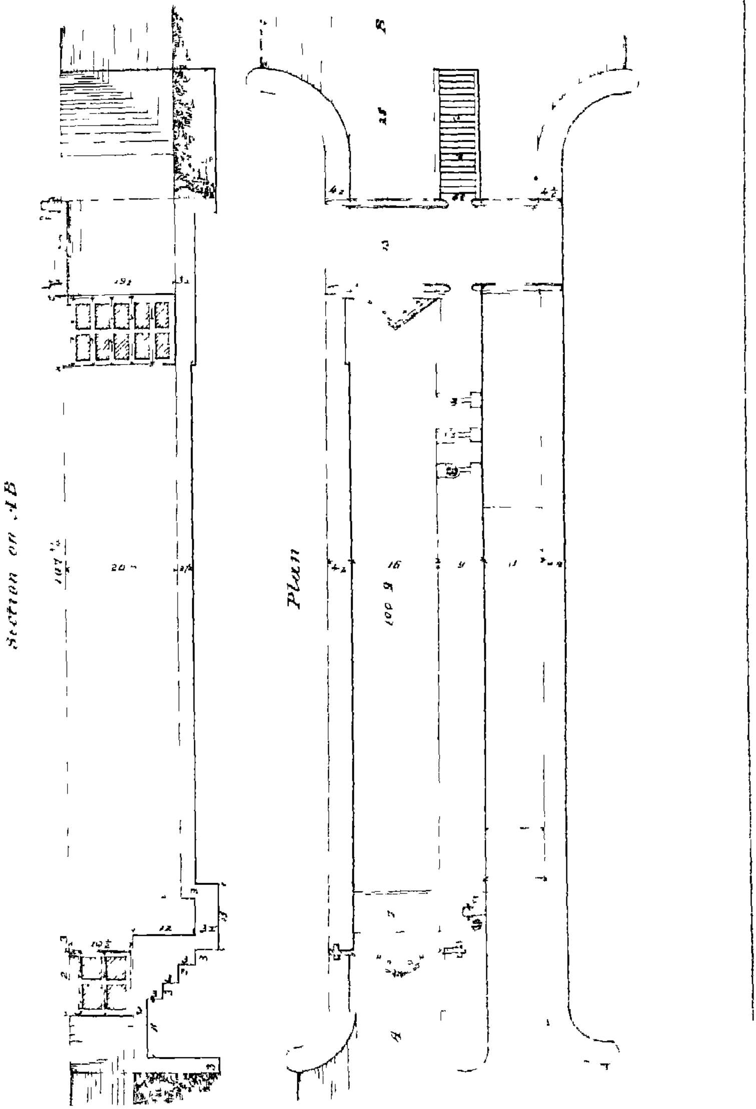


PLATE LVIII

LOCKS GANCES CANAL



one maund in weight each, well packed *on end*, and at a slope of 1 in 15, will *not* stand a mean velocity of 17·4 feet per second.

293. It is clear that navigation must be interrupted by Falls, and *Locks* are therefore necessary for the passage of boats, up or down, the action of which may be understood by an inspection of the Plate. Suppose that a boat has to pass from the upper to the lower level, the upper gate being closed, and the lock chamber being empty. The lower gate is first closed, the sluices of the upper gate are raised by which the lock chamber is filled with water; the upper gate itself is then opened and the boat passes into the lock chamber when the upper gate is again shut. The lower gate sluices are then opened, by which the water in the chamber flows into the lower level, the boat sinking with it; the lower gate itself is then opened and the boat passes out. The process has, of course, to be reversed if the boat has to ascend from the lower to the higher level.

The locks may either be arranged on one side of the main channel in a bay adjoining the falls, or a separate navigable channel may be provided round the falls with the lock arranged at any convenient point on its course. This has been done on the Ganges Canal, but it is an expensive arrangement, and the small channels have been troublesome from their silting up and from the growth of weeds in their beds. The only advantage of the arrangement is to obviate the danger of boats being carried over the falls; but with proper precautions, such as a floating boom across the main channel above the bays of the falls, this danger can easily be prevented.

The size of the lock chambers depends on the sort of boats used and the amount of traffic. On the Ganges Canal they are 100 × 15 feet. If the traffic is heavy, a double set of locks may be required, for the up and down traffic to be worked together.

294. *Mills* for grinding corn, &c., may be advantageously established wherever there are falls on the canal, particularly if in the neighbourhood of a town or large village. A separate channel may be cut for the mill-race, joining the main canal again below the fall. The following is a description of the *Pun-chukkee*, or native corn mill, in general use on the canals in Upper India:—

On the mountain streams and rivers in the Northern *Doáb*, the natives use a water-mill for grinding corn, which for its simplicity is well deserving attention, as it might be applied in all countries where a fall of water can be commanded, and where a want of efficient workmen renders the complicated and expensive species of mill machinery, generally used, a matter of difficulty to manage or keep in repair. In the hands of the natives and with the rude means that they have by them, it may be perhaps considered the only sort of mill that could be turned to any account, both from the absence of any complication in its parts, and from the simplicity of its construction; rendering it in any man's power, for a trifling outlay, either to fix his mill at any point that may suit him, or to remove it at pleasure; the only weighty parts about it being the mill-stones, which however, by running a stick through them, and yoking a bullock or pair of bullocks to them, may in the neighbourhood of roads or common tracks be also removed with as little difficulty or expense as the rest of the machinery.

A horizontal water-wheel with floats placed obliquely, so as to receive a stream of water from a shoot or funnel, the said float-boards being fixed in a vertical axle passing through the lower mill-stone, and held to the upper one by a short iron bar at right angles, causing it to revolve with the water-wheel;—the axle itself having a pivot working on a piece of the hardest stone that can be procured from the shingle near at hand:—this with a thatched roof over it, and the expense and trouble of digging a cut so as to take advantage of a fall of water,—are the only articles required in this very simple mill. The plan is so obviously good, not only for the means gained, but also from the simplicity rendering the whole almost independent of repair, and so intelligible in its parts as to come within the comprehension of the simplest understanding, that it has been adopted generally in all the canals in the Delhi district, as well as in those of the *Doáb;* and with such success, that the introduction of such mills, wherever sufficient fall is provided, is as much an object, on account of the profit arising to the canal returns, as from the accommodation and convenience offered to the community, in providing the means for grinding corn.

On reference to the accompanying Plate, it will be seen that there is only one motion, and that supposing the materials are good, the permanency of the machinery depends entirely on the lower pivot. It will also be evident that there is not a part of the whole machinery that could not be repaired and put in perfect order by the commonest village workman, a matter of importance in the absence of mechanical skill and practised workmen. Whereas in the plainest undershot wheel applied to a mill for grinding corn, there are no less than three wheels of different descriptions; the change of vertical to horizontal motion;—and three pivots to keep in order, with a friction, even under the most skilful management, tending constantly to disarrange the parts, and render the accompaniments of a forge and blacksmith's shop absolutely necessary to keep the mill in order.

On the canals it has been found worth while to construct permanent buildings for these corn mills, and although keeping most strictly to the original simplicity of the machinery, they are set up with greater care, and means are given for regulating the motion, &c., which renders the whole as perfect as it can well be.

It would appear that a fall of water (that is to say, the difference of level between the surface of the head supply and the float-boards of the water-wheel), equal to three feet, is the minimum in which this species of machinery can be used with any good effect; and it has been found that with a fall of three feet, the dimensions of the shoot or funnel require an addition in width, to obtain that by weight of water, which the smallness of the fall will not give by velocity alone, and in the dimensions of shoot given to those of a higher class.

WATER-MILL FOR GRINDING CORN

(as used in Upper India)

Fig 1

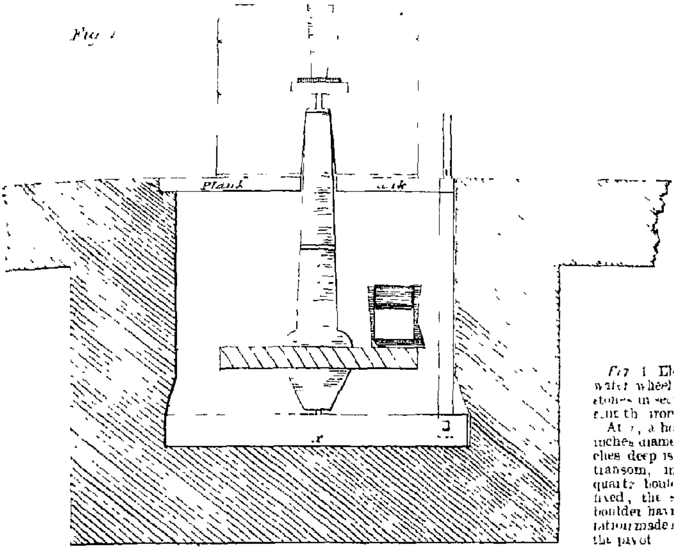


Fig 2

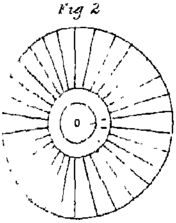


Fig 4

scale of ⅙ inch to one foot

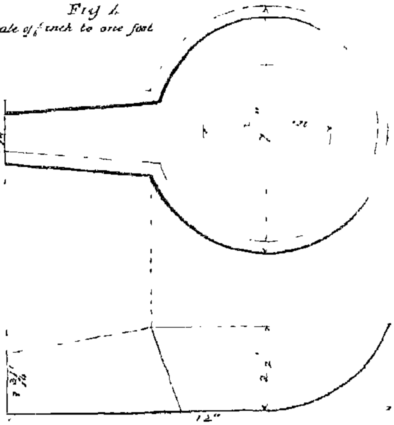


Fig 3 Scale ¼ inch to one foot.

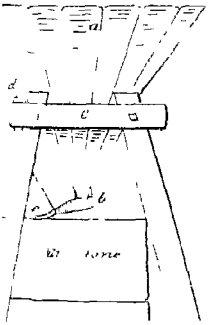


Fig 1. Elevation of the water wheel with the stones in section to [illegible] the iron spindle.

At *x*, a hole of about 4 inches diameter and 4 inches deep is made in the transom, into which a quartz boulder is firmly fixed, the said stone or boulder having an indentation made in it to receive the pivot.

This pivot consists of another stone of the same quality, about 4 or 5 inches long and 1 inch square, which is firmly fixed into the tail of the spindle (see *y*). The above stones are picked up in the beds of the mountain rivers, and are used as they are found without any stone cutting.

Fig. 2. Plan of water-wheel; the float boards of sissoo wood, the float boards 12 inches long with a spoon sunk 4 inches.

Fig. 3. Sketch of mill stones, with basket stand, &c.

a. Hopper or basket.

b. Shoe.

c. Feeder, or small piece of wood hanging to one lip of the shoe, and resting on the mill-stone, each revolution of which gives the shoe a jog, causing the corn to run constantly from the hopper through the shoe.

d. String attached to the opposite lip of the shoe to which the feeder is, and by tightening or loosening which the charge of corn is regulated.

e. Stand.

Fig. 4. Shoe on a large scale: this is generally cut out of a block of dhak (*Butea frondosa*), or any wood easily worked.

The following are the particulars of mills on the Eastern Jumna canal, divided into three classes from the depth of the fall ; the width of shoot on the sill or waste-board, being 12 inches, and the discharge per second averaging 6 5 cubic feet ; the diameter of mill-stones 27 inches, and thickness 12 inches ;—the corn being ground into *atta* or coarse flour.

Class.	*Fall of water.*		*Atta ground per hour.*	
	ft.	in.	md.	seer.
No. 1	7	6	1	26
2	5	6	1	5
3	3	6	0	17

The common mills used in the Jumna and mountain-streams, are said to grind from 5 to 7 maunds of atta per day, or in 24 hours ; the machinery being of the rudest description, the supply of water very small, and a great part of that escaping through the shoot before it touches the water-wheel.

The return to Government on the mills is obtained generally by farming them out to contractors for fixed periods, who pay so much per day as long as a supply of water equal to that entered in the contract is provided, regulated by the depth of water on the sill or waste-board ; this return of course varies not only from the powers of the mill, but also from their position relatively to populous towns and cantonments.

The stones used on the canals are chiefly those from the quarries near Agra, Rúpbas and Fatihpur Sikri, a course-grained sandstone, which requires the chisel every second day—there are three sizes used—

First size, diameter 36 inches, depth 12.
Second „ „ 30 „ „
Third „ „ 27 „ „

The two latter are in most general use. Stones of the usual quality last for about two or three years, that is to say, at the end of that period a new upper stone is provided, and the old one placed below.

CHAPTER L.

DRAINAGE WORKS—AQUEDUCTS—INLETS—DAMS—SUPERPASSAGES.

295. WE now come to the very important class of works by which the canal is carried over the various obstacles to be met with in its course.

The great expense and intricacy of the works in the upper portion of most canals in Northern India, is owing to the number of drainage lines running from the hills, across which the canal has to be carried before it can be brought fairly out on to the general watershed of the country. Of course, so far as it can be laid out, it is made parallel to these lines, and not perpendicular to them, but owing to their numerous ramifications, and to the oblique line at which the canal has to start, in order to get clear of the river before it can be carried on in a parallel direction, it always happens that many of these drainage channels have to be crossed; and as many of them are swollen to formidable torrents in the rains, and all of them are troublesome, the fall of the bed being great, and their course often very shifting, it becomes a matter of considerable consequence how to provide for them.

296. Much may be done by *diversion, i. e.*, by altering their course so as to make them run clear of the canal. A very instructive example in this way was the Chukkee torrent on the Baree Doab Canal, for the passage of which costly works were originally designed. The Chukkee at the time of the commencement of the canal works had two outlets; just above the crossing point of the canal, the main channel divided; one, the larger branch running into the Beas, the other into the Ravee. This latter was embanked across at the bifurcation, by boulder dams and spurs of the same material, protected at the extremity by masonry revetments. By these means the whole of the water was forced to flow into the Beas and the expense of the works for the canal crossing saved.

If, however, the torrent cannot be diverted, it will appear that there are three cases under which it may have to be crossed. 1st, When it is on a lower level than the canal; 2nd, When on the same level; 3rd, When it is on a higher level.

297. In the *first* case when the torrent or drainage line is on a lower level, the canal is carried over it on an *Aqueduct.* The valley drained by the torrent will be embanked across in the usual way, care being taken that sufficient water-way is provided under the aqueduct for the torrent to pass when in flood. Now, an aqueduct only differs from a bridge in having to carry a water channel over it instead of a road or railway. The bridge part may be made of wood, iron or masonry. The channel must be water-tight, and strong enough to carry the water, of course. Sometimes an iron trough is used, but for large aqueducts a masonry channel is usually employed, supported on arches, resting on piers and abutments like an ordinary bridge.

The most celebrated instance of this class of works is the Solani aqueduct on the Ganges Canal.

This work, by which the canal is carried across the valley of the Solani river, consists of an earthen embankment or platform, raised to an average height of sixteen and a half feet above the country, having a base of 350 feet in width, and a breadth at top of 290 feet. On this platform the banks of the canal are formed, 30 feet in width at top, and 12 feet in depth. These banks are protected from the action of the water by lines of masonry retaining walls formed in steps extending along their entire length, or for nearly two and a quarter miles north of the Solani.

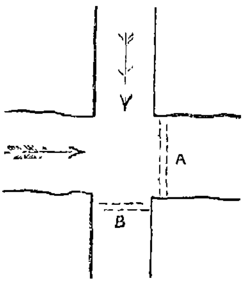
The river itself is crossed by a masonry aqueduct, which is not merely the largest work of the kind in India, but one of the most remarkable for its dimensions in the world. The total length of the Solani aqueduct is 920 feet. Its clear water-way is 750 feet, in fifteen arches of 50 feet span, each. The breadth of each arch is 192 feet. Its thickness is 5 feet; its form is that of a segment of a circle, with a rise of 8 feet. The piers rest upon blocks of masonry, sunk 20 feet deep in the bed of the river, being cubes of 20 feet side, pierced with four wells each, and undersunk in the usual manner. These foundations, throughout the whole structure, are secured by every device that knowledge or experience could suggest; and the quantity of masonry sunk beneath the surface is scarcely less than that visible above it. The piers are 10 feet thick at the springing of the arches, and 12½ feet in height. The total height of the structure above the valley of the river is 38 feet. It is not therefore, an imposing work when viewed from below, in consequence of this deficiency of elevation: but when viewed from above, and it when its immense breadth is observed, with its line of masonry channel, nearly three miles in length, the effect is most striking.

The water-way of the canal is formed in two separate channels, each 85 feet in width; the side-walls are 8 feet thick and 12 feet deep, the depth of water at full supply level being 10 feet. A continuation of the earthen aqueduct, about three-quarters of a mile in length, connects the masonry work with the high bank at Roorkee, and brings the canal to the termination of the difficult portion of its course.

298. The *second* case is where the torrent is crossed on the same level. It may be a small drainage channel only occasionally filled, or at least never bringing down but a small body of water. In that case it simply becomes an *Inlet*, and is provided for by an arched opening through the embankment, by which the water can be passed into the canal. In this way all mere surface drainage is provided for at various convenient points, though as the course of the canal when once clear of the difficult ground above, lies close to the watershed of the country, the amount of intercepted drainage is small.

But if the torrent is of large dimensions and bringing down a great volume of water at a high velocity, the above method will not answer; the the water, loaded with silt, would choke up the canal bed, and its force would destroy the embankments and do irretrievable damage. More elaborate arrangements have therefore to be made, the nature of which will, however, easily be understood from the following diagram.

B is a regulating bridge across the canal channel provided with the usual sluice gates. A is a dam across the channel of the torrent provided with flood gates. Under ordinary circumstances A is closed and B is open, so that the canal water flows along as usual. But, when the torrent is in flood, then A must be open and B closed, so that the flood-water may cross the canal, and run down its own channel. The bed of the torrent below the dam must be paved for a certain length to prevent erosion, and the sides of canal and torrent have to be revetted for a considerable length to prevent their being cut away by the water.



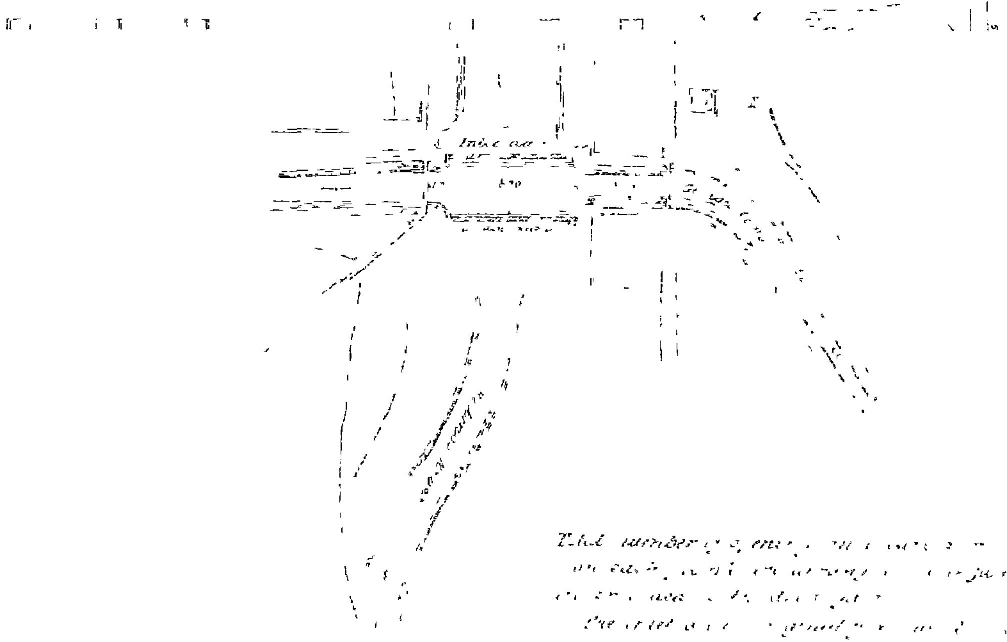
The finest example of these works is at Dhunowrie, on the Ganges Canal, where the Rutmoo torrent is passed.

The dam itself consists of 47 sluices of 10 feet in width, with their sills flush with the canal bed, separated by piers of $3\frac{1}{2}$ feet. The above are flanked on each side by five overfalls of the same width, having their sills raised to a height of 6 feet, with intermediate piers of the same dimensions as those in the centre sluices. On the extreme flanks are platforms raised to a height of 10 feet above the canal bed, and corresponding in height with the rest of the piers. These elevated platforms, which are 17 feet in length, are connected with the revetment esplanade by inclined planes of masonry carried through the flanks of the dam.

[illegible]

GANGES CANAL

Section of [illegible]



Total number of [illegible]

The amount of waterway, therefore, through the sluices, up to a height of 6 feet, is equal to 470 feet in width ; to a height of from 6 to 10 feet, it is increased to 570 feet, and when flood water rises above that height, the water passes over the full expanse of the masonry, which is equal in width to 800 feet.

For the ten sluices on the flanks, the closing and opening is effected by sleeper planks for which grooves are fitted to the piers. For the centre openings, drop gates are provided, which are retained in their upright position by chains against the pressure of the canal water from the inside, and which, on the occurrence of a flood, can be dropped down on the flooring by releasing a catch, and allow the flood water to pass through the openings. When the flood is over, the gates are raised upright by a moveable windlass, the pressure of the water being temporarily taken off by dropping planks into the grooves.

On the down-stream side of the dam, a platform of box-work, filled with river-stone, extends to a width of 43½ feet from the masonry flooring ; this is held in position by double lines of 20-feet piling, strongly clamped together by sleepers fastened on to the upper surface, the slope of which is 2¼ feet on an incline down-stream.

The regulating bridge has ten water-ways each 20 feet broad, and provided with gates, to prevent any flood-water passing down the canal. In addition to this there is a roadway bridge, and about a mile of revetment walls, all resting on blocks of brick masonry, sunk to a depth of 20 feet below the canal bed. The whole of this work is protected by a forest of piles, and an enormous number of bottomless boxes filled with boulders.

By a double tunnel, upwards of 500 feet long, the river, when not in flood, flows *under* the canal.

299. The *third* case is where the torrent crosses on a higher level; when it has to be carried over on an aqueduct, generally called, in that case, a *Superpassage*, to distinguish it from the first case where the canal flows over the torrent. This, of course, becomes a very expensive and troublesome work, as a large water channel has to be allowed to carry any extraordinary flood over the canal in safety, and sufficient head-way must be allowed under the superpassage so as not to interrupt the navigation.

It possesses, however, the great advantage of keeping the canal completely free from any influx of flood-water from the torrents, which is always more or less heavily charged with silt. It has the additional recommendation of not requiring the maintenance of a large establishment every rainy season, as in the case of a level crossing, where the regulating apparatus must be worked by manual labor; and lastly, the canal supply can thus be kept up uninterruptedly, there being no necessity to shut it off at the crossing to keep the silt laden flood-water out of the channel below. These recommendations apply equally to passage by " aqueduct," and render them both generally preferable to a dam when the levels will admit of the substitution.

There are two fine examples of superpassages in the Northern Division of the Ganges Canal, by which the Puttree and Ranipore torrents are crossed. These have a clear waterway between the parapets of 2 and 300 feet, respectively, and when the torrents are not in flood they are used as bridges of communication.

I have preferred however to give a detailed description of the Seesooan superpassage as designed for the Sutlej Canal.

Taking the catchment basin of the Seesooan to be 8 miles in length by 3 miles in width, we obtain an area of 24 square miles, which would give a maximum rain-fall to be carried off of 7,752 cubic feet per second, agreeing very closely with the discharge calculated from the area of the section at the canal crossing, with the velocity due to a declivity of 1 in 794 ; to pass of this discharge, a waterway of 150 feet wide by 6½ feet in depth, on the above declivity will be required.

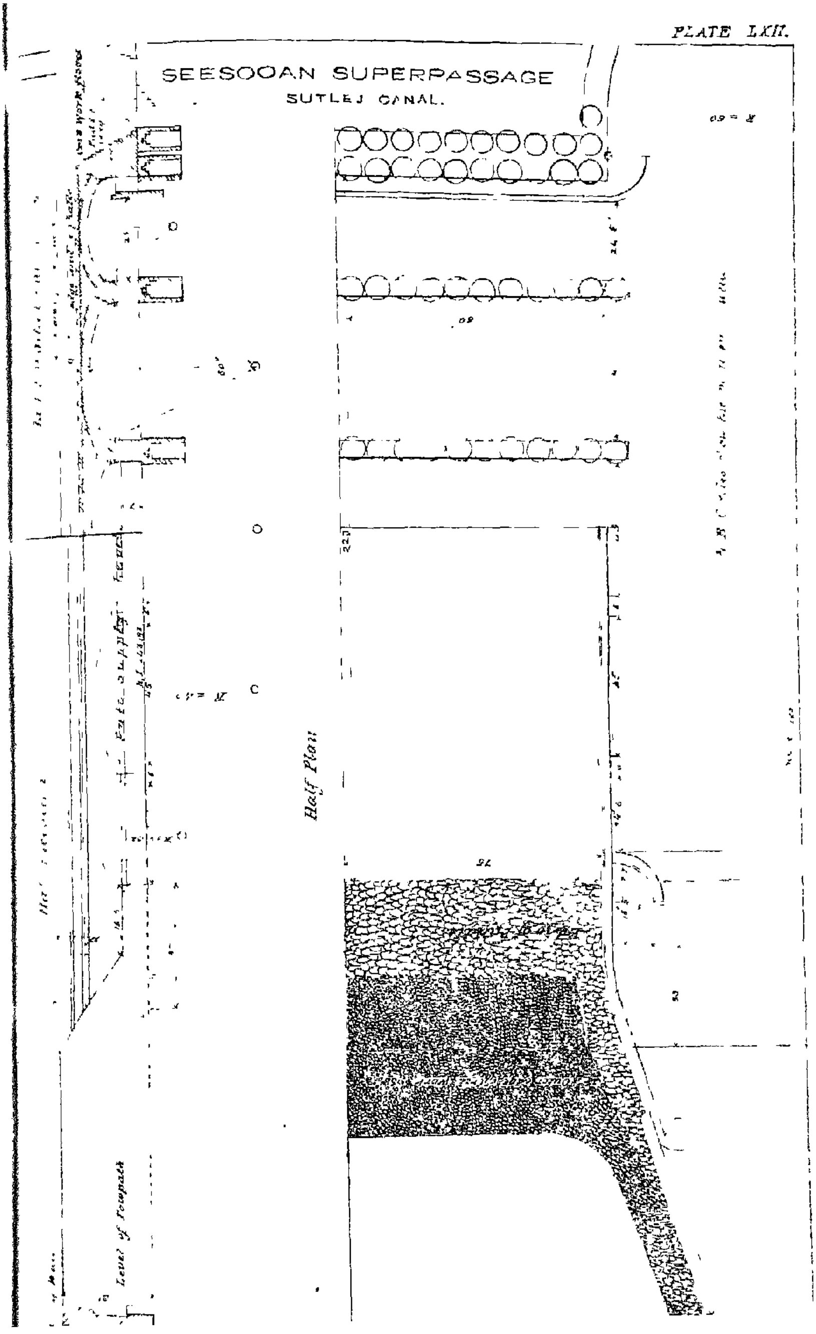
The difference of level between the beds of the canal and the torrent is 21·93 feet, which is thus disposed of :—

Depth of water in canal, ...	7·00
Headway up to soffit of arch, ...	10·00
Thickness of arch, ...	3·00
Brick-on-edge flooring, ...	1·93
Total, ..	21·93

The canal channel will be spanned by three central arches of 45 feet span each, and two at the sides of 32 feet each ; tow-paths 7½ feet wide in the clear will be carried under each side arch, leaving an aggregate water-way of 184 feet The mean waterway of the canal channel is only 177 feet : the addition is made in this work, in consideration of the impossibility of increasing its dimensions should the canal be required to carry a larger supply hereafter. The waterway for the torrent above, is projected in one channel 150 feet wide at bottom, with side walls (head walls of the work) 10 feet in height, 5 feet thick at the base, 4 feet at top ; the flooring over the arches will be formed of asphalte or some substance impervious to water, the upper surface being covered with some hard material, probably a layer of kunkur slabs ; the backing of the abutments will be of puddled clay covered with a flooring of kunkur, slag or boulders, packed in cribs. The foundations of piers and abutments must here be undersunk, the surface of the springs lying some 5 feet above the level of the canal bed, below which it will not be possible to drain. The foundations of the wing-walls need not be carried lower than the bed of the canal at their junction with the abutment, thence diminishing upwards by steps, as shown in the plan ; the tow-path retaining walls being quite separate from the body of the work. and having no weight to support, will not require foundations deeper than 4 or 5 feet, which may be laid in with the aid of pumping ; the wing-walls will be carried out sufficiently far, up and down-stream, to keep floods well away from the edge of the canal excavation ; crib-work revetments, 130 feet in length, with spurs, will be added at their extremities to preserve the banks from cutting and keep the current in the proper channel.

SEESOOAN SUPERPASSAGE

SUTLEJ CANAL.



CHAPTER LI.

HEADWORKS—DAMS—REGULATORS

300. IT remains to describe the works which are required for admitting and controlling the supply of water in the canal, and for distributing it for the purposes of irrigation.

The works at the head consist essentially of a *Dam* across the river, by which the water is held up and checked in its onward flow, and a *Regulator* across the head of the canal channel, by which the proper quantity of water is admitted.

In most cases the canal is taken out of a branch of the main river, and the permanent dam is thrown across the branch only, the water being diverted from the main stream into the branch by temporary dams constructed of boulders, which are swept away on the rise of the river, and are annually replaced. This arrangement has chiefly been due to the very heavy expense which would be incurred in throwing a permanent dam across the main river itself, and perhaps, to a fear of meddling more than is absolutely necessary with the normal flow of such rivers as the Ganges, Jumna, &c.

But the disadvantages of the arrangement are very serious, as will be readily understood with a little explanation. The great rivers rising in the Himalayas are at their lowest during the months of December, January and February. In March and April the increasing heat begins to melt the snow on the high ranges, and causes the river gradually to swell and rise until the month of June, when the periodical rains commence, and the river rises still more in June, July and August, in which last month it attains its maximum, falling rapidly in September, October, and November.

Now, the months in which the water is more especially valuable to the cultivator are February and March, when the spring crop is coming to maturity, and September and October, just before the same crop is sown, *i. e.*, at the two periods when the river is beginning to rise, and commencing to fall. It is, therefore, essential that the temporary dams annually erected should be in position in September (if possible), and should be maintained until April; and, in general, they are so; but it not uncommonly happens that a sudden freshet may breach or sweep away these dams before the river has permanently risen for the season, and when it is too late to replace them. And, it is always difficult to get the dams built early in the autumn, partly from the uncertain state of the river which is very liable to freshets, and partly from its being the most sickly season of the year for workmen.

In each case the valuable rubbee crops suffers, while of course, the annual expense of replacing and repairing these dams is also very great It is more than probable, therefore, that before long, permanent works will be constructed at the heads of all great canals, so as to have the main stream of the river completely under control, and, not merely the branch from which the canal supply is now drawn.

301. Dams are either made solid, when they are called *Wars* (in Madras, *Anicuts* is the local term), or they may be provided with openings as is generally the case in the Upper Provinces; indeed the term dam is always understood to mean an *open* dam in Northern India, or one partly open and partly closed.

The advantage of the *Weir* is that it is *self-acting*, requiring no establishment to work it, and if properly made ought to cost little for repair. It is also a stronger construction, better able to withstand shocks from floating timbers, &c. Its disadvantages are that its first cost is generally greater* and that it causes a great accumulation of silt, boulders, &c, above it and interferes, far more than an open dam with the normal regimen of the river. It is possible that in certain cases, this might result in forcing the whole or part of the river water to seek another channel, and the possibility of this should always be taken into account, but if the river has no other channel down which it could force its way, the accumulation of material above the weir would be an advantage rather than otherwise, as adding to its strength. The finest example of weirs are those erected on the Madras rivers, which will be described further on. The advantage claimed for the open dam is that the interference with the normal action of the river is reduced to a minimum, the strong scour obtained by opening its gates effectually preventing any accumulation of silt above; its first cost too is generally smaller than that of a weir.

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* Not always. The quantity of masonry in a weir is much greater than in an open dam, but the quantity of fine, and therefore expensive work, is less.

302. A *Dam* consists of a series of piers at regular intervals apart, on a masonry flooring carried right across and flush with the river bed, protected from erosive action by curtain walls of Masonry up and down stream.

The piers are grooved for the reception of sleepers or stout planks, by lowering or raising which the water passing down the river is kept under control. The intervals between the piers is generally 10 feet, which is a manageable length for the sleepers. If the river is navigable at the head, one or two 20 feet openings fitted with gates must be provided to enable boats to pass.

The flooring must be carried well into the banks of the river on both sides to prevent the ends of the dam being turned, and the banks and bed of the river will generally require to be artificially protected for some distance, above and below the dam, to stand the violent action of the water when the gates are partially closed.

The two flanks of the dam for some length are generally built as weirs; that is, instead of piers and gates the masonry is carried up solid to a certain height, so that when the water rises above that height it may flow over the top of it. The advantage of this arrangement is that it affords an escape for water in case of a sudden flood when the dam may be closed, while, when the water is low, they keep it in the centre of the river and away from the flanks, and thereby create a more perfect scour.

When the river is subject to sudden and violent floods, damage might be done before the sleepers could be all raised, one by one; it is better therefore to employ flood or *drop-gates* in such a case; that is, gates which turn upon hinges in the piers at the level of the flooring and which when shut are held up by chains against the force of the water. In case of flood the chains are loosened, the gates drop down, and the water flows over them. Should the intervals between the piers be over 10 feet, there would be a difficulty in hauling the gates up again.

A bridge of communication may be made between the piers of the dam if required. But as it is not desirable to have it obstructed with traffic, it may be merely a light foot bridge, or the intervals may be spanned temporarily with spare sleepers.

The dam and regulator are generally close together and conected by a line of revetment wall.

The *Regulator* like the dam consists of grooved piers resting on a firm foundation carried across the *canal* bed. As floods are made to escape down the river, and are shut out from the canal, flood-gates will not be necessary for the regulator, and the water may be admitted and controlled either by planks alone, or as is usual, by a gate moving up and down in the grooves—on to which planks can be dropped when necessary, one by one The gates are raised or lowered by a windlass and chains; the windlass may be moveable, or one may be fixed between every two piers and worked by handspikes.

The piers of the regulator are generally connected by arches so as to form a regular bridge of communication across the canal.

The bed and banks must be defended by masonry as in the case of the dam, so as to be safe from the water's action when the gates are open or only partially closed.

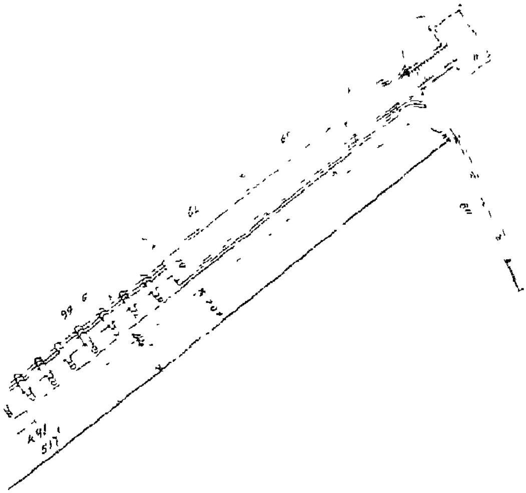
The flooring of the regulator at the head of a canal is a convenient datum for all the canal levels. A water-gauge should be fixed on it at one of the piers, so that the amount of water passing into the canal may be accurately known.

303. The following is a description of the dam and regulating bridge at Myapore, the head of the Ganges Canal, shown in the annexed Plate:—

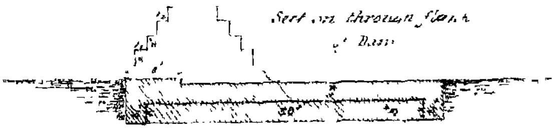
The dam, which is 517 feet between the flanks, is pierced in its centre by fifteen openings of 10 feet wide each ; the sills or floorings of each opening being raised 2½ feet from the zero line. These floorings are so constructed, that if necessary, they may be removed, and a flush waterway be obtained as low as zero. The piers between the above openings are 8 feet in height, so that the elevated flooring leaves the depth of sluice-gate equal to 5½ feet. The piers are fitted with grooves for the admission of sleeper or vane planks.

The centrical sluices are connected to the flanks by overfalls, rising in gradations of one foot on three series ; the overfall nearest to the flank being raised 10 feet above the zero point. The flank walls themselves are 18¾ feet in height, exclusive of cornice and parapet, which rise 5 feet above them. The top of the overfalls on the right and left, as well as that of the piers, is flat ; the former being an esplanade varying from 7 to 10 feet in width, which, during dry weather, is connected by a temporary communication formed by planks thrown across the sluice openings. This esplanade is at each extremity terminated by a flight of steps, which gives access to store-rooms ; in which, when the dam is laid open, and the woodwork removed, the latter is lodged for security. The two buildings for this purpose are situated on the flanks ; their floors are raised 20¼ feet from the zero point, and their interior dimensions are 30 feet in length by 16 feet in breadth.

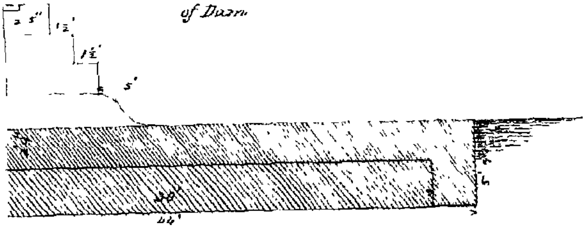
PLATE LXIII



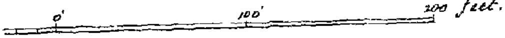
Section through flank of Dam



Section through Pier of Dam



Scale.



The flank revetments, which are built on the right and left of the down-stream side of the dam, and between which the escape water has to pass, have been designed with an inclination inwards equal to 13 feet on a length of 80 feet.

The transverse width of the dam platform is 44 feet, measuring from the up to the down-stream face of the work. Of this measurement 20 feet 11 inches are given to the tail, which delivers the water upon the natural bed of the river, consisting of large boulders and shingle.

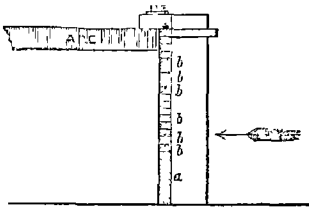
The revetment which connects the right flank of the dam with the regulating bridge, is a plain wall equal in height to the dam flanks, and with a slope or batter of 2½ in 20 feet in height. This revetment, on its approach to within 50 feet of the bridge, terminates in a line of ghât, or flight of steps, which passes from the higher levels to the bed of the canal. The up-stream wing or flank of this flight of steps corresponds in form with that of the wing of the bridge, with which it has a uniform curve.

The regulating bridge has ten bays or openings of 20 feet wide and 16 feet high ; each bay being fitted with shutters and apparatus for either opening or closing it. The breadth of the platform on which the piers rest is 48 feet, exclusive of the cut-waters, which project 4 feet beyond it. The roadway is 37 feet 9 inches wide between the rear parapet and the up-stream front windlasses ; it acts as the main line of communication between Hurdwar and Kunkhul.

The design of shutters for closing the regulators is different to that which has been practised on the Jumna canals ; it affords much greater facilities for working, and secures either the closing or the shutting of the bays in a much shorter period of time.

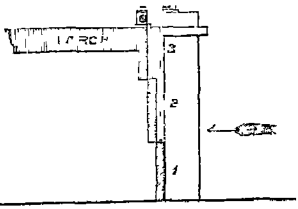
On the Jumna regulators a drop gate is used in a simple groove, and sleepers with a scantling of 6 inches square are dropped upon the top of the gate. Both time and labor are required to close or open the bays when fitted with apparatus of this sort, but it has always acted very efficiently ; and opposed to the Jumna floods, has done its duty very well. On the Jumna canals, however, there was not the same volume of water to contend against, nor the same number of bays to open and shut, that exist on the works which we are now describing : and it was necessary, with ten bays upon which the safety of the works depended, to devise some quicker method than that which acted for three, and, if possible, to economize the labor required for using the apparatus. The following diagrams will show in vertical section the method which is in use on the Jumna, and the improved method which was adopted in the present case.

Fig. 1.



Old Method on the Jumna.

Fig. 2.



Improved Method on the Ganges.

Fig. 1, it will be observed, represents the groove and its cutwater opposed to the up-stream current, '*a*' represents a gate 5 feet in depth, which is kept [illegible] in dry seasons and is dropped down on the expectation of floods, *b*, *b*, *b*, [illegible] sleepers or long bars of timber, which when the chains are removed from the ga[illegible] are successively dropped upon them until the bay is closed. The time that this takes is equal to eighteen minutes.

Fig. 2 shows the improved design, gained by the use of two windlasses. The b[illegible] or opening, it will be observed, is divided into three series, the more advanced one having its sill on the zero level; the centrical and rear ones having their sills elevated in heights of 6 feet, retrograding towards the face of the bridge. The shutter marked No. 1 is dropped from a windlass on the bitt-head 1; that marked No. [illegible] from the bitt-head 2; that marked No. 3 consists of sleepers, which are raised and lowered without the aid of a windlass. The three gates, therefore, are quite independent of each other; each has its own sill to rest upon; and the whole can, if necessary, be worked simultaneously. The great advantage of this method will be understood, by supposing that a supply of water not exceeding 6 feet in depth is required for canal purposes. In this case, the whole of the shutters 2 and 3 may remain closed; and when floods come on, the whole of the water-way may be stopped by releasing one set of gates only.

The machinery attached to these gates is of the most simple description, intelligible to the commonest laborer on the works, and not liable to disarrangement. It consists of windlasses, which work in sockets embedded in wooden bitt-heads, with ratchet wheels and catches; the windlasses being turned by hand-spikes. The chains are on the bar principle, in lengths of 3 inches, with plain rivets, and the shutters are mere planks, strung upon iron rods, held at their lower ends by nuts, and terminating above by rings countersunk for fixing the chain upon. The wood used is saul (*Shorea robusta*), the staple timber of the Sewalik forests.

304. The above description may be understood to apply to all regulators employed on the canal, as well as to the one at the head. Thus there will be a double regulating head where each branch is taken off, one regulator being fixed across the head of the branch line to admit the necessary amount of water which the branch is calculated to hold, and the other being built across the main channel at the same spot. By the simultaneous working of the two it is evident that the water will be perfectly controlled.

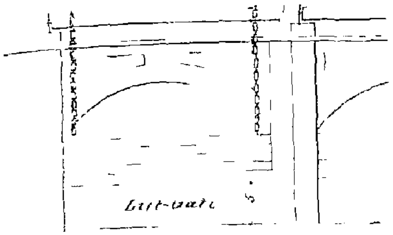
Regulators of smaller size will also be required at the head of each *Rajbuha* or principal water-course, where it is taken off from the main line for irrigating purposes. A single opening will generally be enough, and gates sliding up and down in the grooves of the abutments may be worked by a ratchet and lever, or a windlass with spokes.

305. But in order to establish a complete control over the water in the canal channel, provision must be made for any excess which may arise from sudden rain floods or from the water not being always required for irrigation. This is effected by means of *Escapes*, which are short cuts from the canal to a river or other natural water-course, into which the ex-

CANAL REGULATING APPARATUS.

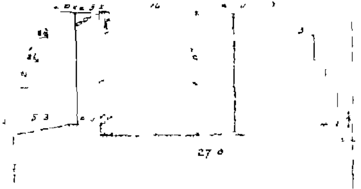
Regulating Bridge with Lift gate & sleepers

Elevation.

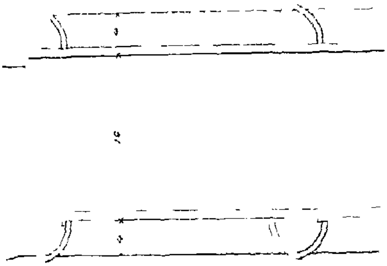


Drop gate for Dams

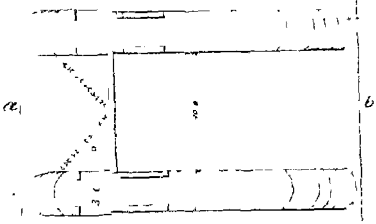
Elevation



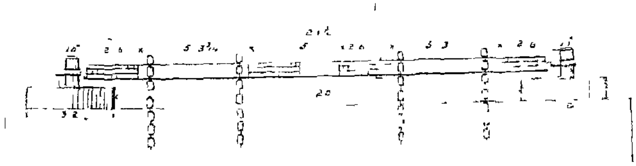
Plan



Plan



Windlass for Regulating Bridge



Plan of Sleeper

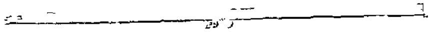
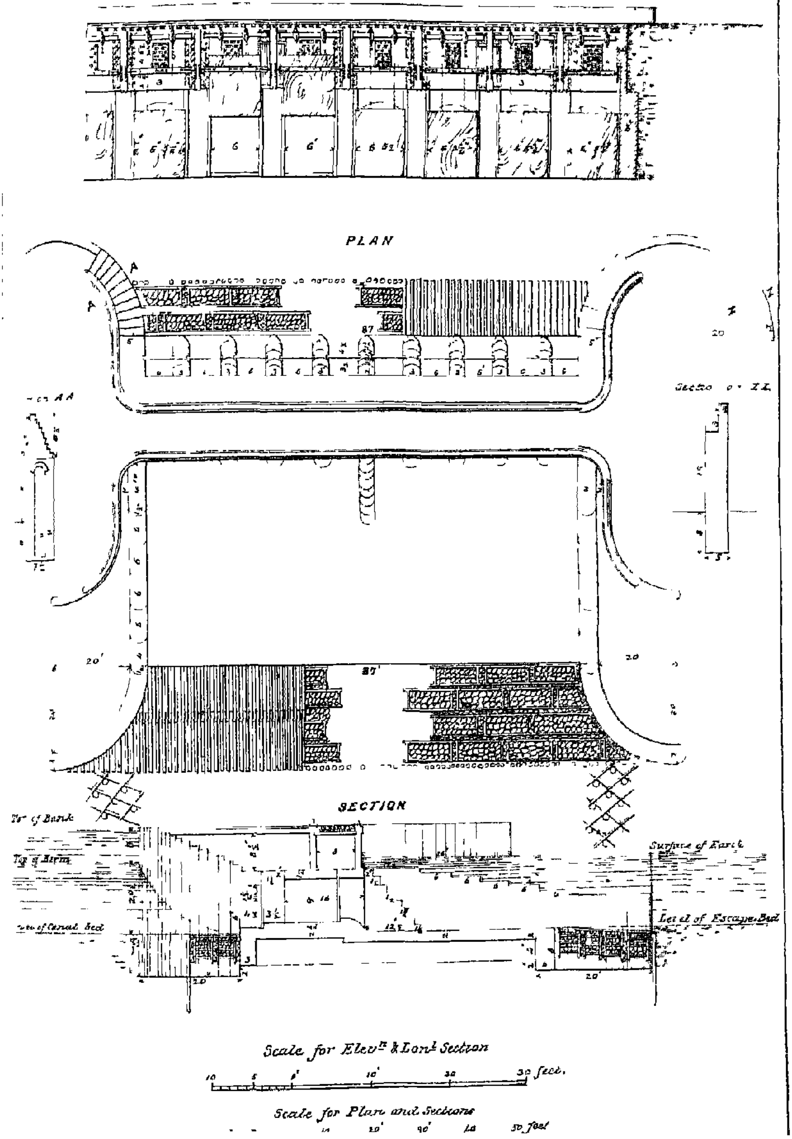


PLATE LXV.

KHUTOWLI ESCAPE HEAD.

(GANGES CANAL)

Elevation and Longitudinal Section Interior of the Khutowli Escape.



ess of water can be discharged. Escapes, it has been well said, are to a canal what safety valves are to a steam engine. They should be provided at certain intervals all the way down the line, and a double regulating head should be built at the point where the escape is taken off, as in the case of a branch canal. On the Ganges Canal they were projected at about every 40 miles, but much must depend on the convenience with which they can be made, that is, on the proximity of the canal to the river or water-course into which the escape is to be conducted. They should also, if possible be provided at all dangerous points, such as above a long line of heavy embankment; where, in case of the bank bursting, great damage would ensue. The cut should be made large enough, and with sufficient fall, to carry off the whole body of water that can reach that point, so that, if necessary, the canal below the escape may be at any time laid dry for repairs, without stopping its running above—by opening the escape regulator and shutting down the corresponding one across the canal. By this means also that part of the canal above the escape may be opened when completed, while work on the lower portion can proceed.

306. The following is a description of the Khutowli Escape Head on the Ganges Canal, at the 62nd mile, the escape itself being an excavated channel 60 feet wide at the head and 3½ miles long.

The masonry head consists of 10 openings of 6 feet in width each, their height from flooring to the soffit of the arch being 8½ feet; the flooring is raised 2 feet above the canal bed in gradations depending on the working of the gates and sleepers. The transverse width of the flooring is equal to 64 feet, 40 of which form the tail which is laid on a slope (inclining down-stream) of 1 foot from the level of the canal bed. The flanks of this work are protected by masonry revetments, and the usual guards of piling and rubble work, with which the floorings are also covered and protected from the wear and tear of the current on its approach and departure, by boxwork aprons.

In consequence of the magnitude of the canal embankments at Khutowli, and the elevation of their upper esplanade, which is 20½ feet above the canal bed, the apparatus for opening and shutting the sluices has been covered by a line of building, the roof of which corresponds with the higher levels, and, therefore, acts as a roadway, without interrupting the communication on the bank. The supports for the windlasses, which consist of upright timbers placed in the form of a cross, act also as supports to the roof, and give great additional strength to the building. It will be seen by the plan, that the chains attached run over an upper roller, by which the whole water-way is relieved, by the gate being drawn up through the slit made in the flooring, and raised as high as the roof: the design is of the simplest description, it is exceedingly strong, and from its being protected from the weather, and from disturbances arising from the other causes, it is hoped that the working will be very efficient.

CHAPTER LII.

RAJBUHAS—MEASUREMENT OF WATER—IRRIGATION DETAILS.

307. The distribution of the water, it has already been explained, is effected by means of *Rajbuhas* or principal water-courses, which are small branch canals with a masonry regulator at the head, from which the cultivators make their own water-courses to their fields. On the older canals, irrigation was carried on from the main channel itself, the water-courses being constructed by the Zemindars; but the inconveniences arising from this practice were found to be so great, arising chiefly from waste of water, that the rajbuha system is now generally adopted. In this system we may, as Sir Proby Cautley remarks, consider the canal as answering to the Reservoir or supply channel in the water-supply of towns; the rajbuhas or Distributaries as the Mains, and the village water-courses as the Service channels.

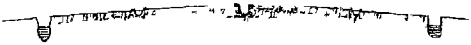
The rajbuhas, constructed on the most approved system, form a continuous line of irrigating channel on each side of the main canal, and generally parallel to it. This line is fed by cuts from the main canal at regular intervals (say three miles) apart, wherever the levels of the ground admit of it, and in the rajbuha are fixed the heads of irrigation of all the village water-courses, which are made by the villagers themselves.

The rajbuhas are laid out by the Canal Engineers, and are under their exclusive control for maintenance and repair, but on some of the canals they are still the private property of the Zemindars, who either advance the money for their construction, or repay it to Government if (as is generally the case) it has been made with Government funds in the first instance But it is in every way desirable that the rajbuhas should be considered as part of the first cost of the canal, even if a higher water-rate has to be charged to cover the expense of their construction.

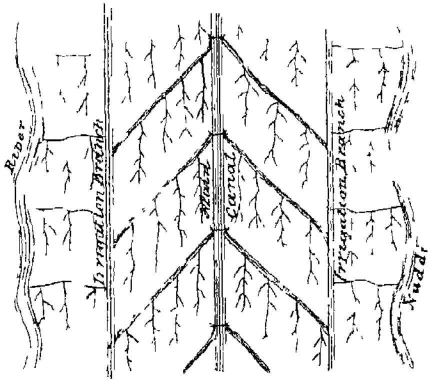
PLATE LXVI

RAJBUHAS.

General arrangement of Canal and Rajbuhas

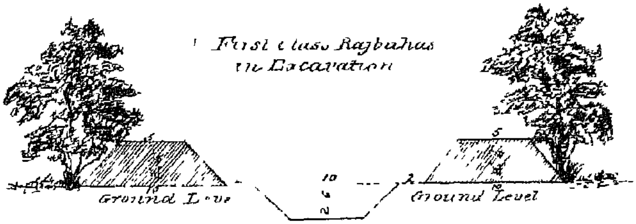


Section

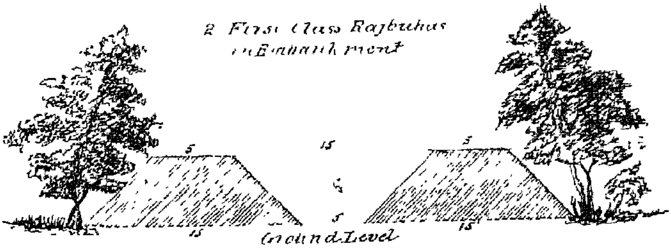


Plan

1 First Class Rajbuhas in Excavation



2 First Class Rajbuhas in Embankment



308. The level of the bed of the rajbuha should be fixed rather with reference to the full supply level of the canal than to the level of the canal bed, chiefly because it is an object to keep the rajbuha bed at a sufficiently high level to admit of surface irrigation on its whole line as far as possible. Moreover, the nearer from the surface that water is taken off by a rajbuha head, the less will be the silt which enters the rajbuha and the less the annual labor of clearing the bed. The bed of a rajbuha will, therefore, generally be from 1 to 3 feet higher than that of the main canal.

Its section may be as shown in the Plate.

The declivity should be regulated as far as possible by the maximum velocity of current which the soil will stand without cutting away, and as the body of water is much less than in the main canal, the slope of the bed may generally be greater—2 feet a mile is not too much.

If *falls* are rendered necessary by the profile of the country, they must be provided on the same principle as those on the main line, and it is even advantageous to have one at the point where one rajbuha tails into another, to get rid of back-water and prevent the accumulation of silt. Escapes are also advisable where they can be provided.

Rajbuhas may be cleared of silt twice every year, viz., in April and October, or when the water is least required. The floorings of all bridges and other masonry works built over them, will of course have been carefully laid down to the proper levels, and will give so many permanent bench-marks for restoring the correct level of the beds.

309. The* greater the amount discharged by a rajbuha the smaller will be the proportion of cost of maintenance to the revenue derived. This is evident, when we consider that, "*cœteris paribus*," a channel 12 feet wide discharges more than double the volume delivered by two, each 6 feet wide, and consequently has more than twice their irrigating capacity, while the cost of patrolling and repairs to banks on the first will be just one-half that on the two last. The carrying powers of large volumes of water being also greater, the deposit of silt in the 12 feet rajbuha will be more gradual than in the 6 feet channels, thus doing away with the necessity of frequent clearances. The actual amount of clearances during the year is also diminished, for a great portion of the silt which would be rapidly deposited at the head of a small line, is carried along and dropped into the water-courses branching off from a large one. The labor of clear-

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* This paragraph in taken from a Memorandum by Major Brownlow, R.E., late Superintendent of the Eastern Jumna Canal.

ance is thus in some measure thrown on the cultivators, who would have to pay for it in any case, but by whom it is much more cheaply performed than by the Government working parties. For the above reasons, Major Brownlow advocates the adoption of capacious heads for rajbuha channels, the limit of discharge being the ability to control the volume of water in case of a breach. Experience seems to prove that irrigation may be safely and most profitably carried on from channels 18 feet wide at bottom, with side slopes of 45°, depth of water being 3½ to 4 feet, provided that the bed be kept at least 2 feet below soil for the first ten miles of its course, and that no outlets be allowed in subsequent embanked portions of the line. Also that no rajbuha maintained by the Government should have a less width than 6 feet at head. On the Eastern Jumna canal during 1858-59 and 1859-60, the revenue from all rajbuhahs of 12 feet head water-way and upwards, amounted to rupees 1,29,618·76, while the expenditure on their maintenance was rupees 16,038·05, or ·123 of the revenue. The revenue from all rajbuhas *below* 12 feet water-way at the head was rupees 2,67,049·83, and cost of maintenance, rupees 56,579·87, or ·223 of the revenue, being very nearly double the proportion in the first case.

The economy of water on the large channels is equally marked, for, during the above named two years we find the revenue from

7	rajbuhas	of	12 ft.	head water-way	and upwards,	Rs.	1,29,618·76
49	„	of	6 „	„	„	„	2,16,432·86
29	„	of	3 „	„	„	„	50,616·97

giving an average revenue per annum of

Rupees	9,258·48	from a rajbuha	of 12	feet	head water-way.
„	2,208·58	„	of 6	„	„
„	872·70	„	of 3	„	„

Measurements made in 1855 gave 86, 32, and 22 cubic feet, as the relative discharges in cubic feet per second from 12 feet, 6 feet, and 3 feet heads on this canal; but subsequent measurements suggested a modification of the proportion to 90, 32, and 22; adopting which, we have as the relative values of a cubic foot of water per annum—

Rupees	102·87	on 12	feet	rajbuha.
„	69·50	„ 6	„	„
„	39·65	„ 3	„	„

or 10 : 7 : 4.

The increased action of absorption and evaporation on the small chanbeds, with diminished volumes and feeble sluggish currents, accounts for the difference above shown.

The *depth of water* in rajbuhas should never exceed 4 feet, but in carrying out a new line of irrigation we should aim at keeping the surface of water at about 1 to 1½ feet above the general surface of country, so as to secure irrigation by the natural flow of water. Under these conditions breaches in the banks need never be feared, with ordinary care in their construction and maintenance. This object, however, is to be kept in due subordination to the primary desiderata of a reasonable longitudinal slope, and an alignment following the watershed of the country.

Where the existing supply on a rajbuha becomes insufficient for the demand, it will be in the end found more economical to increase the discharge by widening the original channel for a suitable distance, than to do so by carrying the required additional volume down from a second head as is often done; against the latter course all the arguments before adduced hold good, while the back-water from the head which is running the strongest, is sure to check the velocity of water in the other, and so immensely accelerate the deposit of silt.

Two heads may under peculiar circumstances be required for a rajbuha, but in such a case, their junction should be at least two miles from the main canal, and Major Brownlow dissents from the general opinion that the necessities of irrigation require a rajbuha being thus provided. With ordinary energy and arrangement, a channel can be cleared of silt at the head in four or five days, and not even rice will suffer by being deprived of water for that time if care has been taken to give it a good watering previous to the closing, which timely warning to the cultivators will always ensure.

The rajbuhas on the Eastern Jumna canal have longitudinal slopes of all inclinations from 4 feet to 6 inches per mile. The former is however too great and the latter too small; 2 feet per mile is perhaps the best slope to give, and no great inconvenience is experienced with slopes of 1 foot per mile, but below this the deposit of silt and contraction of channel from growth of weeds become most annoying in small rajbuhas.

The system of raising water to the level of the country where it runs below the surface of soil by *stop dams* or *planks*, introduced into grooves, constructed for the purposes, cannot be too strongly condemned. These convert what should be a freely flowing stream, into a series of stagnant, and unwholesome pools, encourage the growth of weeds and the deposit of silt, and are in every way objectionable. Besides, with a reasonable slope in the surface of the country, it will be generally found that for every beegah of irrigation thus secured, ten can be obtained further on by the natural flow of water. Be this, however, possible or not, it is decidedly better to resort to any other means of raising the water to the level of the country than the above wasteful and unhealthy expedient.

The following statement shows cost of maintaining the rajbuhas on the Eastern Jumna canal during 1858-59 and 1859-60, including share of establishment payable from tuccavee account:—

Year.	Cost of repairs.	Water-rate.	Area irrigated.	Total length of channels.
	RS.	RS.	RS.	Miles.
1858-59	39,443·64	1,66,378·16	2,46,410·45	601·71
1859-60	36,729·52	2,45,205·70	3,63,983·75	
Mean,	38,086·58	2,05,792·28	3,05,197·10	601·71

From which we deduce the following average results; per centage of repairs on water-rate, 18·50 or 2 annas 11½ pie per rupee; cost per beegah irrigated, rupees 0·125 or 2 annas; cost per mile of channel, rupees 63·29.

The expenditure on rajbuha repairs has been much reduced of late, by the system of driving at furlong distances across the beds of these channels, a line of stakes with their heads at correct levels of bed. Uniformity of slope is thus ensured, measurements of silt clearance are easily checked, and a momentary glance shows whether the work has been efficiently performed. At least once a year, the bottoms and side slopes at the ends of long lines of irrigation, should be scraped and cut away to the proper section, as nothing hinders the progress of water and encourages the growth of weeds so much as irregularities of bed.

The rajbuha heads have already been described; those on the Eastern Jumna canal are 6 feet wide; while the feeders are 3 feet. The capacity of channel has of course to be fixed with reference to the slope and amount of water required, the latter being determined by the area of land requiring irrigation.

310. The village water-courses receive water from the rajbuha by means of *kolabahs*, which are long wooden* tubes with a rectangular transverse section of fixed dimensions running under the rajbuha banks, being closed when required by a sliding wooden shutter. They should be fixed rigidly in a horizontal position and at right angles to the rajbuha bed; the bottom of the kolabah being slightly raised above the level of the latter.

The *Irrigation outlets*, or "*kolabas*," on the Eastern Jumna canal are of two kinds. "Full," measuring, 8″ × 10″ (the latter dimension being vertical); and "half," measuring 8″ × 5″. The conditions of discharge vary indefinitely with each outlet, but 2 cubic feet may be assumed as the average volume delivered by a full, and one cubic foot as that delivered by a half, kolaba, per second.

Kolabas on the Eastern Jumna canal were formerly placed at various heights above the rajbuha bed, diminishing from 1 foot near the head to 3 inches or less, at the tail, with the view of equalising, in some measure, the head of water on each. But in practice this plan was found most inconvenient, as during periods of small expenditure of water, it became necessary to run nearly a full supply in rajbuhas to give the kolabas at the head any water at all, and the channels at the tails of long lines became so gorged that breaches in the banks were sure to ensue. Besides, the exterior conditions of discharge vary so much as to nullify in a great measure all interior arrangements. The outlets are therefore, now built all flush with the bed, by which means the irrigators at the head can obtain water with a low supply in the rajbuha, and any extra advantage thereby gained can be compensated for by longer "tateels" when necessary.

311. When the supply entering the head of any irrigating channel becomes insufficient for the demand, it is necessary to distribute the water fairly by closing or diminishing the supply entering the outlets near the head for a certain time, and thus forcing it down to the tail. Such a closing of outlets is known as a "*tateel*." It is better not to impose a "tateel" on rajbuha heads, but to regulate the supply entering them according to the demand lower down the canal. The advantages of a constant but moderate supply in rajbuhas are, that embankments are kept moist and are thereby less liable to crack and be breached by water, and that the growth of grass and weeds in the bed is checked. On the Eastern Jumna canal, it is the custom to allow 9 inches of water to fall over the upper edge of the planks in the grooves of a *first* class head (6 feet water-way), and 6 inches over the upper edge of those in grooves of a *second* class head (3 feet water-way). When the supply thus admitted is insufficient for the demand on the rajbuha, "tateels" are placed on the kolabas near the head for certain fixed periods. Where tateels become an established custom, as they must do on every fully developed system of irrigation, it is advisable to impose them over long portions of a rajbuha at once, and to fix certain days of the week for their maintenance. Short lengths of tateel have very little effect, besides being nearly as troublesome to watch as long ones, and zemindars will remember days of the week who cannot be brought to recollect dates. On the Eastern Jumna canal, notices of tateels are given to irrigators who close their kolabas of their own accord at the appointed time. On long lines, the outlets on the first length (near the head) are closed for four days of the week, and on the second portion for three days, thus ensuring a permanent though moderate supply to those at the tail. Water-courses more than three miles long are allowed to run at all times.

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* Whenever possible the tube should be of more lasting material than wood. Earthenware pipes set in concrete, with masonry ends, are now generally used.

312. Field irrigation is known as *Tor* or *Dál*,* according as it is, or is not, surface irrigation. In the former case the water flows over the fields through cuts in the banks of the water-course which are then closed. In the latter case it is raised or thrown on to the land, usually in a primitive manner by men with shallow swing buckets and ropes. Of course less is charged for water supplied to land where the levels do not admit of tor irrigation.

313. Water-rates are assessed on the area irrigated, and vary according to the nature of the crop and the amount of water it requires. A separate arrangement and payment is either made for each harvest, or a contract is made for a certain number of years. The measurements are made by the Canal Officers, and the amount due by the different villages is recovered by the Collector of the district.

The *Water-Rates* of the Eastern Jumna canal are assessed on the irrigated area of different classes of crops. The measurements of these areas are conducted by the Zillahdars, and checked by a "darogah of measurements." During October and April of each year, each Zillahdar commences measuring up the irrigation of the preceding fusl. Four chains are enough for one man to look after; each chain requires two "mirdas" and a "mohurrir." The area measurement by one chain in a day varies of course with the size of fields and nature of crops. Khureef crop, 100 beegahs; rubbee, 200 beegahs. Canal beegahs = 165 feet square = 3,025 square yards = $\frac{5}{8}$ acre. Measurements made with chain of 82·5 feet divided into 10 guttas of 8·25 feet, subdivided into 10 kurries of ·825 feet.

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* *Torna* to break (the bank). *Dalna* to throw (the water).

The measuring party is accompanied by the chokedar, who points out the irrigation, and by the lumberdar or putwarree of the village, who gives the name of the cultivator. All measuring parties should be frequently *visited* by the Executive Engineer and his Assistants, who should personally verify the accuracy of the work previously completed.

314. It is clear, however, that the fairest method of charging payment for water is to sell it as one would sell any other article; that is, according to the quantity taken. It cannot make any difference to the canal proprietor what becomes of the water after he has once issued it and been paid for it, and to have to enquire to what purpose it has been put before he can fix or receive its price, is naturally productive of vexatious interference, and unnecessary expense and delay. Unfortunately, however, the difficulties in the way of delivering water by measurement have hitherto been found insuperable, chiefly because no practical method has yet been hit upon of measuring the water under a head of pressure constantly varying; for not only does the surface level of the water in the main channel continually change according to the amount of water taken off above, the amount of rain-fall, &c., but the deposits of silt at the head of the distributing channel would also cause the quantity discharged to vary continually.

The ordinary form of orifice through which water is discharged for irrigation is rectangular or circular, the orifice being set vertically in the side or end of the channel forming the source of supply. Thus, if AB represent the level of water in a canal, and x an orifice through which that water issues, as long as the level is uniform the cultivators will receive an uniform supply. Let us suppose a cultivator pays for a continuous discharge through an opening with the water standing in the source of supply one foot above the centre of discharge x. In other words his contract is for his orifice to remain open, and for Government to maintain the supply at the depth Ax, or one foot.

Now, the velocity with which a fluid issues from an orifice is as the square root of the depth of the centre of discharge of that orifice below the surface of such fluid. In the case of a small orifice its true centre and its centre of discharge may be taken practically to be the same Therefore, should the surface level instead of being one foot above x, happen to fall 9 inches, the cultivator would receive merely *half* his due, whereas that level must rise 3 feet, or four times the preceding amount to give him *double* his due.

315. What the Italians have done to obtain an uniform discharge, as explained in Colonel Baird Smith's work, may be summed up in very few words. Instead of irrigating directly from the source of supply, they make use of an intermediate chamber, EF; AB being the source of supply, the water is retained by the wall G, which is fitted with the lifting sluice gate Hx. This sluice gate is lifted or depressed by hand, so as to maintain the water level EF, in the next chamber, uniform, and at the standard level, and as long as this is done, and there is a fall out of the chamber EF, the cultivator gets exactly what he pays for.

This apparatus, however, is very imperfect. It only mitigates the evil mentioned above, and affords no protection against the carelessness or dishonesty of the officials whose duty it is to work the sluice gate Hx, raising and depressing it as the head pressure of water in the canal varies. It has, however, the practical advantage of enabling the cultivator to satisfy himself that he obtains his rights more easily, by watching the water level EF, than by examining the height to which the sluice Hx is lifted; to do which, to any purpose, he must understand, and have access to the information possessed by the canal servant regulating the discharge.

It is evident that to give an uniform discharge, contraction of the orifice or water-way must take place in proportion as the depth of water increases. And Col. Goodwyn proposes to employ a cone fitting into a circular orifice which by means of a pully and balance float should sink as the water rises and rise as the water sinks, so as always to allow the same amount of water to flow through the annular space round the cone. I am not aware that this has been fairly tried, and should almost fear it would be too delicate for actual use, but it has been found by a long series of experiments to be practically correct within a very small fraction.

In the project for the Soane canals the rajbuha heads and village watercourse heads are on the plan of the Italian module for measuring water, as

MEASUREMENT OF WATER.

Fig. 1.

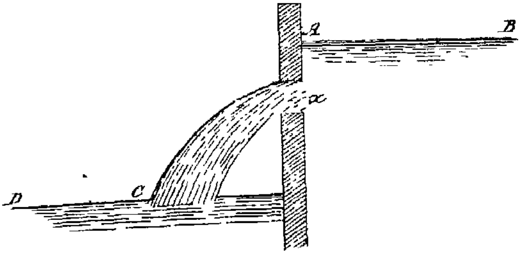


Fig 2.

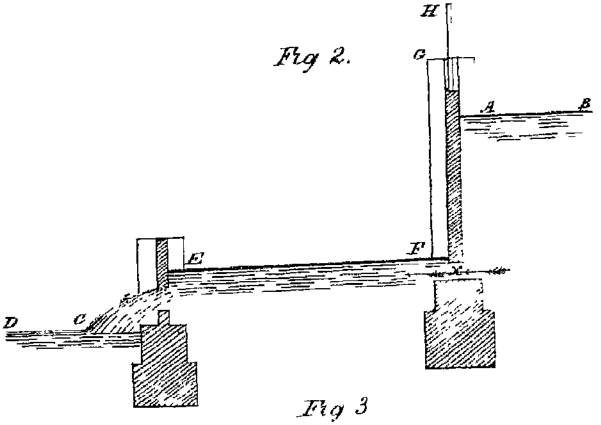
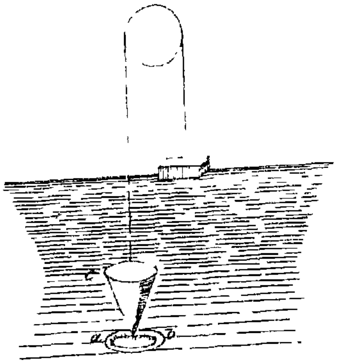


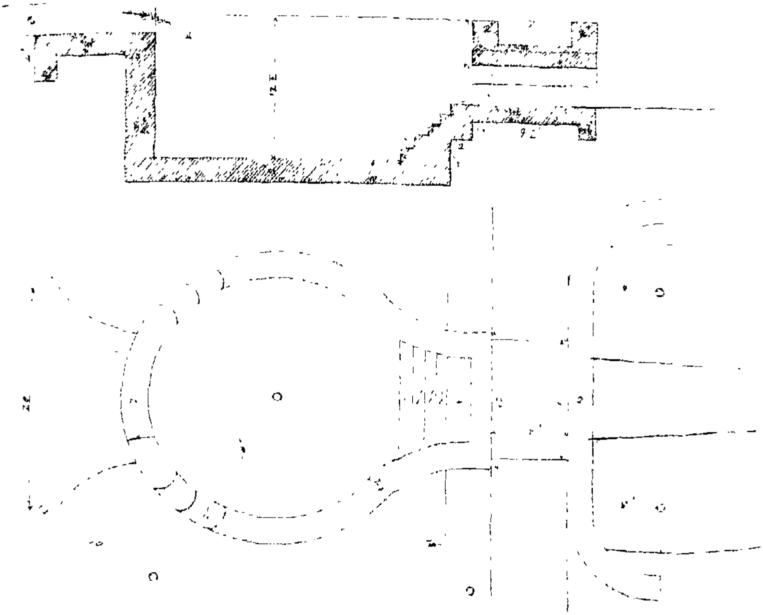
Fig 3



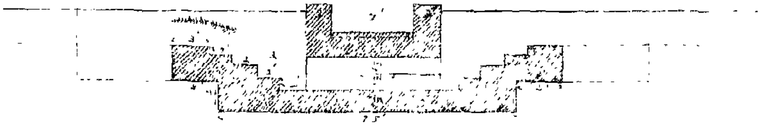
DETAILS OF DISTRIBUTARIES,

As designed for the Soane Canals

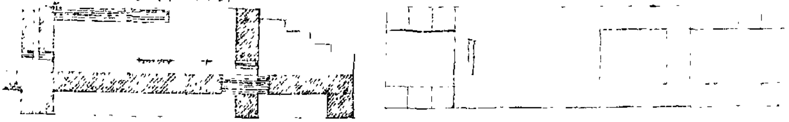
Fall on a Distributary with aqueduct over tail



Syphon Drain for passing one Distributary under another or under, or over a drainage channel

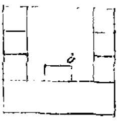


Village water course Head for measuring the water withdrawn from the Distributary.

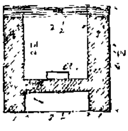


Longitudinal Section. *Plan inverted*

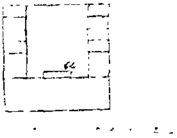
Head Elevation.



Centre Cross Section.



Tail Elevation.



described above, *i. e.*, to reckon the water by the discharge under a given head which is known by the ordinary hydraulic rules, either (1) when the discharge takes place freely into the air, or (2) when it is simply a descent from an upper to a lower level.

The latter method is the one used. In both cases the front sluice board is used to admit such a supply as shall just keep the level of the water in the interior chamber at the mark denoting the desired head of supply. But on the village water-course heads it would be impossible to supervise the working of the head sluice board. It can only be used to shut off the supply when the water is not required. The level of these water-course heads must be so placed that when the intended supply of water is passing down the rajbuha, every village water-course may just have its proper supply, as contracted for. The regulation must be attempted only at the rajbuha head, and the Government will lose a portion of the tail surplus, and the other villages or cultivators gain it, when one or more villages or cultivators let their modules remain closed.

316. The following is a description of a new water Module, invented and patented by Lieut. Carroll, R.E., which is now being tried on the Ganges Canal, and which promises to be the most successful yet invented.

To the mouth of the kolaba a valve is attached of the form and dimensions shown in the Plate, and which may be made of brass or iron.

Its mode of action is very simple. When the plate which hangs in front of the tube is down, the quadrant which is attached to it, is at its highest point, and it will be seen that a free water-way exists through the tube and between its under lip and *the plate in front. If the plate be raised the quadrant sinks into the tube, and* reduces the water-way in proportion to the angle the plate is raised through.

Now, if it be desired to obtain an equal discharge while the head of water in the the canal varies from 3 feet down to 1 foot, the plate is weighted so that the force of the issuing stream at a 1 foot head shall be just unable to move the plate outwards. As the head rises above this the velocity of the stream becomes greater and drives out the plate, thus reducing the water-way till, at a 3 feet head, the plate will remain at a very high angle, and the quadrant will close a great part of the water-way of the tube. The curve of the plate is so adjusted that it shall rest at such an angle as to give the same discharge as at a 1 foot head; when this is done, it is found that at all intermediate heads the discharge remains almost the same. Experiment gives 1 per cent. as the ordinary deviation from exact equality. This module can be equally well applied to regulate under lower heads such as from 1 foot to 3 inches, but requires lighter weights and some other simple adjustments.

The merits claimed for this module are simplicity, cheapness, non-liability to derangement or choking, and the ease with which it can be protected from injury by enclosing it in a small masonry or iron chamber.

be cut so as to give the pymanah or parts of a pymanah that may be required. To do this, the only dimension in the outlet that varies, is the length, which for one pymanah is 1 foot, for five duswas 5 inches, for one duswa 1 inch, and so on. When less than a pymanah is applied for, the head should still be built with the dimensions for a full pymanah, and the actual quantity required should be given through a measuring outlet of the necessary size. It is highly probable that all who begin with small demands for water will in time desire to increase them, and when they do, it will only be necessary to take the stone out of the masonry, cut the aperture to the larger size desired and then replace it, all the rest of the irrigation head remaining as before. When more than one pymanah is required, it will only be necessary to provide a larger stone, and to modify the other dimensions of the head to suit it.

The standard of linear measure to be the foot, decimally divided.

The standard of superficial measure to be the square foot, divided as above.

The standard of cubic measure to be the cubic foot, divided as above.

The standard of land measure to be the canal beegah of 55 yards square or of 3,025 square yards, divided into 20 ghuntas, each containing 151·25 square yards. 1·6 canal beeghas make one acre, and 1,024 make one statute square mile.

The standard of time to be the second.

The standard of work done in irrigation will for the present be 300 beegahs per annum for each pymanah of water. This is nothing more than a rough average given to facilitate the general adjustment of the capacities of channels to the areas they are to irrigate. The precise determination by experiment of the quantity of water required for the irrigation of land under different crops, is a matter of very great importance, and every officer who can add to our knowledge of such details will do a most valuable service to the canal. In giving the above standard it should be considered, not as a good one, but as the best to be extracted from the information as yet accessible on the subject.

The standard formula for calculating discharges in *open* channels to be Dubuat's, or

$$V = (\sqrt{r} - 0{\cdot}1)\left(\frac{307}{\sqrt{s} - \frac{1}{2}\,Nap.\ Log.\,(s + 1{\cdot}6)} - 0{\cdot}3\right)$$

Where V is the mean velocity in inches per second, r the mean radius obtained by dividing the transverse section of the stream in square inches, by its perimeter (omitting the breadth at the surface) in linear inches, the length of the surface of the current whose height is unity (= cose angle of slope).

The standard formula for calculating discharges in *closed* channels and under pressure, will be the following:—

$$D = \frac{2}{3} ml \left\{ (h + p)^{\frac{3}{2}} - p^{\frac{3}{2}} \right\} \sqrt{2g}$$

Where

D = discharge in cubic feet, or practically in pymanahs, per second.

m = constant of contraction which for all ordinary cases, may be taken at 0·60.

l = length of measuring outlet in feet.

h = height of ditto, ditto.

p = head of pressure above upper edge of outlet in feet.

g = 32·174.

Tables have been drawn up to facilitate calculations by both the above formulæ.

318. The papers which will be required in settling each contract for water are the following:—

1*st.* *Khusrah Ab Pashee*, or irrigation field list.

2*nd.* *Teerij Ab Pashee*, or distribution list of the irrigated lands among the proprietors or cultivators paying water-rate.

3*rd.* *Jummabundee Ab Pashee*, or water-rate roll, showing the amount that each individual has to pay under the different heads for which any payments on account of the canal may be claimable from the village These heads are—first, Water-rate as fixed by the terms of contract; second, tuccavee (advances)* for original construction of the rajbuha, which will be recoverable by such number of instalments as may be determined on by Superintendents in each case. In an approximate way the delivery of one pymanah of water through means of rajbuhas will cost in capital the sum of rupees 350, and so soon as a village has paid this sum, it may be absolved from all further claims on account of original construction of rajbuhas, provided, of course, its consumption of water is limited as above Any increase would be paid for at the rate of rupees 350 per pymanah. and this payment would give a perpetual right to the use of the rajbuha

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* The tuccavee system of advances has recently been abolished. Zemindars wanting new water courses, must either make them themselves, or else lodge the estimated cost in advance with the canal authorities.

Provision should be made for the recovery of the original expenditure on rajbuhas within five years from the time when any contractor enters into the rajbuha association. This would give a charge for contracts at the rate of rupees 46 per pymanah for the khureef, and rupees 24 for the rubbee, or in annual contracts, rupees 70 per annum.

4th. *Tuccavee* for repairs and maintenance of rajbuhas. Which should not exceed from 4 to 6 annas, per beegah, annually.

5th. *Tuccavee* miscellaneous, which will include charges for minor items, such as building irrigation heads, drainage, and the like.

6th. The *Theka Ab Pashee*, or irrigation contract, in which the various terms agreed upon between Superintendents and Lumberdars contracting for villages will be recorded.

On sanitary considerations no water shall be issued from the Ganges Canal for the irrigation of khureef crops within the following distances from inhabited places.

From military stations, 5 miles.

From native towns, containing more than 10,000 inhabitants, 1 mile.

From native towns, containing more than 5,000 inhabitants, half a mile.

From large villages, containing more than 1,000 inhabitants, quarter of a mile.

From villages, containing less than 1,000 inhabitants, 200 yards.

And for the purposes of this rule the distance specified shall be measurable from the outermost houses forming part of the station, town, or village, concerned.

It shall be competent to Superintendents of Divisions, with the sanction of the Director, to refuse to grant water for irrigation, in localities which appear naturally to possess a malarious character.

CHAPTER LIII.

DUTIES OF CANAL ESTABLISHMENT.

310. The following extracts from Colonel Baird Smith's instructions, above quoted, slightly altered to suit recent changes, give a brief summary of the duties of Canal Officers.

Revenue.—The general management of all details in the revenue department of each division of the canal is vested in the Executive Engineer. He is responsible for the first formation of the contracts with Zemindars, for the judicious apportionment of the water-rates, and for the prompt realization* of the amounts due by each village to the Government. It is further his duty to see that the revenue records of the division are complete and kept with neatness, safety and scrupulous accuracy. He is also responsible for the efficient administration of the miscellaneous canal revenue, and it is to him that the chief Government will look for the gradual increase of this, by the establishment of additional mills where they are required, the careful disposal of canal bank produce, and the encouragement of traffic on the canal. To enable him to discharge his revenue duties efficiently, the Executive Engineer was formerly invested with the powers of a Deputy Collector, under which he was competent to employ all the means sanctioned by the regulations for enforcing the prompt settlement of the Government demands, excepting only that if he considered it expedient to proceed against the real property of defaulters, he had to address a requisition to that effect to the Collector of the District, within which the said property was situated.

In subordination to the Executive Engineers, the Assistant Engineers of divisions are, after acquiring some experience, authorized to exercise the same powers as the Executive Engineers themselves, on the responsibility of the latter.

The principal native agent of the Superintendent in all revenue matters whatsoever, is the *Zillahdar*, and on his efficiency, the working of the canal revenue system in detail almost entirely depends. All the vernacular records and accounts are prepared under the order of the Executive Engineer by the Zillahdar and his establishment, and through him those measures which were necessary for the realization of the canal revenue were taken. He watches over the distribution of the water through the agency of the chokedars, and brings all defects therein to the notice of the Executive Engineer.

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* This last duty now devolves on the Collector of the district.

Considering the important duties entrusted to Zillahdars, only men of known respectability and good character should be employed. They should be personally active, intelligent and well versed in accounts. If they are acquainted with the land revenue system of collection and accounts, it will be an additional recommendation to them, as the canal system is in all essential particulars, almost identical therewith.

The Zillahdar and his establishment should be employed only in revenue matters. It may occasionally and on emergency be expedient to use them in connection with the works, but as a general rule, the less they are diverted from their legitimate functions as revenue officers, the better are those likely to be performed.

The Zillah *Chuprassies* are intended to assist the Zillahdar in making minor collections, or such other general work of the kind as may have to be provided for.

Police.—The general supervision of the Police arrangements of divisions rests with the Executive Engineers, and on their judgment and vigilance the efficient protection of the works and water of the canal mainly depends.

The powers of Executive Engineers for the above purposes are clearly and simply defined in Act VII. of 1845.

While the general Supervision of Police, in common with all other arrangements, rests with the Executive Engineers, Native *Deputy Magistrates* have been appointed in some divisions, with the special object of relieving the Executive Engineer from the details of work of this kind. These officers have the same powers as the Executive Engineers themselves, but every order they may pass is liable to revision by Executive Engineers, if appealed against within ten days from the date of issue.

The Assistant Engineers may also be made use of in managing the Police details of their respective subdivisions. But Executive Engineers should be careful to satisfy themselves that young officers of this grade are competent to use their powers with judgment, discretion, and due consideration for the Zemindars, before permission is given to them to exercise such powers.

The *Zillahdars* have the same powers as subordinate officers of corresponding grade in the district civil Police. They can collect evidence in all cases included within the Canal Act, and report on the same to their proper superiors, but they have no power to punish, and the exercise of their capacity to enquire should be carefully scrutinized, and every approach to the use of improper means to extract evidence should be summarily and severely checked.

The *Chokedars* are the private Policemen of the canal. It is their duty to watch the works and the water within their respective beats, that neither be damaged in contravention of the Rules. They report through the Zillahdar to the Deputy Magistrates, or Assistant, or to the Executive Engineers, as may be most expedient in each case, and in accordance with the subsidiary rules which may be issued in each division by the Superintendent thereof.

The most frequent offences are the following, which are given in the order of their frequency, beginning with the most common of all, viz.:—

1. Trespass by cattle.
2. Stealing water.
3. Wasting water.
4. Obstructing channels.
5. Wilful damage to works.

These are all punishable by fine or imprisonment.

320. To the above may be added some practical hints extracted from a Memorandum by Major Brownlow aleady quoted:—

General duties of Establishment.—An Executive Engineer should not tie himself down by assuming direct charge of works or administration of any particular portion of canal, but reserve himself for general supervision free to move wherever his presence may seem desirable. Having once distributed subordinate charges to the best of his ability, let him avoid as much as possible frequent changes in their extent or "personnel." These tend to unsettle the establishment and render it difficult to apply past experience or to trace and check irregularities. They deprive a good man of much of his interest in his work and of his acquired local knowledge, while a bad one is seldom benefitted by change of air; "cœlum non animum mutant." The exceptions to this rule will be noted hereafter.

As a rule all necessary orders should be given through the officer in charge of the work under inspection and not to his subordinates. When one of the latter is present and the former absent, the temptation to break this rule is often great, but except in urgent cases it is best adhered to, a contrary practice being decidedly subversive of discipline and good order. All orders especially to natives should be clearly conveyed in writing.

A Superintendent should constantly place himself in communication with Zemindars and villagers, unattended by the usual train of native officials. Then and not till then will they fearlessly state their grievances. He should transact all business in the vernacular as publicly as possible, and be perfectly accessible at certain fixed hours of every week day.

Anonymous petitions should never be listened to, but the repetition of open and acknowledged complaints, even though apparently disproved or grossly exaggerated is a symptom not to be disregarded. They show that something is annoying the people, and though most natives will on slight foundation build up an astounding accusation, villagers will seldom go out of their way to trump up a totally groundless complaint.

Assistant Engineers should be held responsible for the maintenance in working order at a reasonable cost of the sub-divisions entrusted to them; for police arrangements and for proper distribution of water. To enable them to check their expenditure on current repairs and original works, they should ledger it up roughly every month, (including cost of materials at Central Office rates,) the Executive Engineer keeping them distinctly informed of total sums allotted to each account. They should be personally acquainted with the principal Zemindars irrigating from the portion of canal in their charge, and with the characters and capabilities of all their native subordinates. They should know the number and irrigating capacity of outlets on each rajbuha entrusted to them. Should "tateels"* not have been previously established they should arrange them when necessary and see that they are strictly adhered to. They should take every opportunity of verifying the accuracy of any measurements of irrigated land that may be going on in their vicinity. A young hand is apt to suppose that when once his rajbuhas are in good order he need not often inspect them, than which there can be no greater mistake. They may be in admirable order, but constant inspection will do more to keep them so than many working parties. "The master's eye is worth a dozen hands."

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* The closing of outlets at the head of any line of irrigation in order to force water down to the tail is meant by a "tateel" (see above).

On the Eastern Jumna canal the *Native Deputy* is employed as a general rule in moving up and down the line, deciding the numerous petty disputes about water that are constantly arising, and where necessary, punishing infractions of canal regulations. He also checks the work of any measuring parties in his neighbourhood, inspects the Zillahdar's books, and makes himself generally useful. Thus employed he has been always found an invaluable assistant, and I have never found it advisable to localise his duties by placing him in executive charge of a sub-division.

A good *Zillahdar* is a man whose importance cannot be overrated. He is the right hand of his superior in all matter connected with irrigation He should know personally all the principal irrigators and owners of outlets, and be known by almost every resident in his Zillah (the latter being no bad test of his locomotion). He will know at any time where irrigation is going on, and pretty accurately to what extent, and consequently to what points water should be forced down his rajbuhas by "tatoels." At the same time that he is watching the irrigation of the current *fusl* (harvest), he will be supervising measurements of irrigation or collection of revenue for the past one. On the Eastern Jumna canal each Zillahdar has an average of 200 villages, and 250 square miles of country over which to superintend irrigation, measure it up, and collect the revenue. His office books should be carefully kept up and frequently inspected and signed by the Executive and his Assistants.

Sub-Overseers are chiefly employed as purely executive officials on maintenance, or construction of works, but can be made most valuable auxiliaries in superintending irrigation. A good man should have much influence in his beat and be looked up to by the cultivators as second only to the zillahdar. The average charge of a Sub-Overseer on the Eastern Jumna canal, is about 10 miles of canal and 40 miles of rajbuha channels, with their dependent irrigation.

The influence of *Chokedars* for good or bad is so great that too much pains cannot be taken in selecting them, and in keeping their "morale" at the highest pitch attainable. I have always found promoted mates or tindals of working parties make the best chokedars, as they are generally hardy active fellows, and can in case of emergency get repairs executed quickly and well; men of the "mirda" caste, from their aptness at estimating areas and acquaintance with land measurements, make good raw material, but great care is required in selecting them; from living in the large towns they are apt to be loose idle fellows. The uniformity of pay and small prospect of promotion in this grade, led to a proposal being made to Government for increasing the pay of the most deserving chokedars on this canal as an inducement to exertion, and this measure, if sanctioned, will I am confident be productive of immense good. It is perhaps advisable to change these men from one beat to another about once in two years, as it does not take a man long to get acquainted with his new charge, and they are apt if left too long in one place to make private arrangements for the distribution of water, decidedly detrimental to canal interests.

Their average charges should not exceed 5 or 6 miles of rajbuha or canal channel, and 10 to 13 square miles of country, over which to supervise irrigation, as otherwise a man cannot go out to distant points and return the same day to his chokie, having carefully inspected the intermediate irrigation.

Police and Revenue.—Superintendents and their Deputies have powers of an Assistant Magistrate for the protection of canal property and these powers cannot be too cautiously wielded. A firm and vigilant Superintendent will seldom have occasion to punish severely, as irregularities are easily checked at the outset. A Superintendent should be most cautious in accepting the assertions of his native subordinates that such and such villagers are irreclaimable scoundrels, and should occasionally call to mind a pithy native proverb, "The darkest place is under the lamp."

The most common offences are, grazing cattle on canal banks, making ghâts across rajbuhas, breaches of "tateels," and stealing water from another person's water-course. In the first case the chokedar can drive the cattle to the nearest pound, and if opposed (as is constantly the case) he must let them go as soon as they are off the bank which is all he cares about. Where grazing is persisted in and damage done, it is patent and visible; the grass and perhaps some young trees are trampled down or slopes of earthwork are injured. Summon the people who are in the habit of grazing on the adjoining land, show them the injury done and take from them a "moochalka" or bond, that they will prevent the like in future or be liable to a fine not exceeding 50 rupees. The canal authorities on their part can put up a good fence.

Where ghâts are made by foot passengers across rajbuhas, there is no use in fining (at least I have never found it stop the practice); so, accept the situation, and place a couple of stout straight logs alongside of each other across the channel. People infinitely prefer going dry shod to wading through the water, and will consequently abandon the ghât for the bridge. I may here mention that no earth or brushwood should be allowed on a log bridge, as they are liable to fall into and choke up the rajbuha channel; the best plan is to purchase a suitable tree in the nearest village, halve and dress the trunk placing the two pieces side by side. Where cattle are driven across the rajbuha it is generally a sign of a village road having been left unprovided with a bridge, and the sooner one is built there the better.

In dry seasons, breaches of "tateel" are very common, and can only be put a stop to, by constant and unexpected inspection of the lines on which "tateels" are in force, and severe punishment of all offenders, commencing with the canal establishment, who are pretty nearly sure to be in fault. Where a cultivator is accused of stealing the water from another man's water-course, a moment's inspection will verify the truth of the statement, as the breaches in the sides of "kool" are apparent, as also the signs of irrigation. In such cases settle the dispute by a village "punchayet," or take a "moochalka" from the defendent, to the effect that he will in future obtain permission before doing the like. All over the Eastern Jumna canal the payment to the owners of a water-course of *one anna per beegah* on all land irrigated from it by non-shareholders is an established custom.

The taking a "moochalka" from a villager, has, as far as my experience goes, a certain inexplicable influence over him, which renders it a much more efficient restraint than a fine. Only it must be taken for a reasonable amount and invariably realised on a breach of the agreement contained in it.

The practice of issuing "dustuks" for realisation of revenue has been entirely put a stop to on the Eastern Jumna canal. Apart from the eccentricity of notion that a man who cannot or will not meet a demand for a certain amount, is at all likely to pay readily the "tulubanâ" in addition to the original demand, "dustuks" are objectionable as offering great inducements to zillahdars to provide for needy relatives, at the expense of the irrigating community, and four years' experience has now proved them perfectly unnecessary. Notices can be issued to defaulters, warning them, that if satisfactory arrangements for paying up arrears are not made within a certain time, their moveable property will be attached.

When the Superintendent is found to be as good as his word in two or three instances, the threat has seldom to be carried out.

The collection of water-rate for any "fusl" should invariably be cleared off before the end of the ensuing one. Mill-rents should never be more than ten days in arrears, and fines should be realised immediately on infliction, otherwise they fail to answer their purpose as deterrent punishments and sink into a most objectionable source of revenue.

CHAPTER LIV.

COST AND REVENUE.

321. THE *Cost* of a permanent canal will evidently vary according to its size, the difficulties attending its construction, and the varying rates of labor and materials in different localities. It will be useful, however, to collate the experience derived from canals already constructed, or projected, so as to gather some idea of the *average* cost of such projects.

The total cost of the Ganges Canal when completed according to the original design (and including Rajbuhas) will probably be 250 lakhs.* Its estimated full discharge is 6,750 cubic feet per second. Its total length will be 900 miles. This gives a cost of Rs. 3,704 per cubic foot of discharge, or Rs. 27,778 per lineal mile.

The Baree Doab canal will probably cost Rs. 1,35,00,000 ;† is calculated to discharge 3,000 cubic feet per second, and will be 469 miles long, giving an average of Rs. 4,500 per cubic foot, or Rs. 28,784 per lineal mile, exclusive of rajbuhas.

The Eastern Jumna canal has cost Rs. 16,78,000, being 134 miles long, and discharging 1250 cubic feet per second, thus averaging Rs. 1,342 per cubic foot, or Rs. 12,522 per mile, excluding rajbuhas.

The Western Jumna canal has cost Rs. 21,29,000 ‡ for a total length of 445 miles and a full discharge of 2500 cubic feet, being Rs. 852 per cubic foot or Rs. 4784 per lineal mile, excluding rajbuhas.

The Sutlej Canal is estimated at Rs. 1,10,19,000, (exclusive of permanent dam at the head,) for 530 miles, and a full discharge of 3500 cubic feet, being Rs. 3,148 per cubic foot or Rs. 20,790 per mile, without lockage; and exclusive of rajbuhas.

The Soane Canals are estimated at Rs. 1,35,72,000 § for a length of 826 miles, and a discharge of 3124 cubic feet, being Rs. 4,344 per cubic foot or Rs. 16,431 per mile; inclusive of rajbuhas.

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* Rs. 2,12,98,000 to end of 1863-64.

† Rs. 1,08,89,000 to end of 1862-63.

‡ To end of 1863-64.

§ Excluding the cost of the permanent dam at the head which amounts to Rs. 18,00,000 more. The length of this canal is much greater in proportion to the discharge than that of the others.

Excluding therefore the Jumna canals, which were not entirely new projects, and assuming that the cost of rajbuhas will be Rs. 1,000 per mile, and that there will be three miles of rajbuhas to one of main canal channel, it would appear that a first class canal of Irrigation when complete, with rajbuhas, will cost on an average Rs. 4,200 per cubic foot, per second, of maximum discharge, or about Rs. 25,000 per mile of length.

The above may be considered to include the whole cost of first construction, including establishment; while the establishment for maintenance, with the cost of annual repairs, will afterwards of course become an annual charge or drawback upon the revenue.

322. *Revenue.*—This is derived first and chiefly from *Water-rent* which, as said above, may be charged on the amount of water distributed or the area of land irrigated.

The following are the rates for water now in use on the Ganges Canal:—

		Tor.			Dál.		
		RS.	A.	P.	RS.	A.	P.
1st Class.	For Sugar, per annum, per acre, ...	5	0	0	3	5	4
2nd Class.	For Fruit, nursery and vegetable gardens, singharas, cultivated grasses, lucerne, guinea grasses, &c., ajwain and similar herbs, rice, ...	3	0	0	2	0	0
3rd Class.	For indigo, cotton, tobacco, wheat, oats,	2	4	0	1	8	0
4th Class.	For Indian corn, safflower, cheena, barley, gochnee, oil seeds, jowar, Pulses of all kinds, ...	1	10	8	1	0	0

Villages taking water from the canal for irrigation are exempt from all charges for watering their cattle and for water required for domestic purposes. Other villages pay for watering cattle, 6 Rs. per 100 per annum. For watering sheep or goats, 2 Rs. per 100 per annum. For filling tanks (not irrigating) the water is paid for at 1 rupee per 6,000 cubic feet in bulk.

Transit dues are fixed from time to time for boats or rafts plying on the canal.

Other scources of revenue are from *Corn mills*, which are built by Government, and rented annually to the highest bidder.

Canal produce, such as grass, &c., also sold annually. *Fines* for breaches of canal regulations, such as stealing water, trespass, &c.

On the Baree Doab canal the standard of area measurement is the *Kunal* of 4,500 square feet, and the charge for water at present is 4 annas per kunal per annum or crop for *Tor* irrigation, and 2 annas for *Dál*.

On the Soane canals the expected water-rent was reckoned at Rs. 1-9-0 per beegah, per annum, for the two crops, or Rs. 1-12-2 (equivalent to Rs. 2-8-10 per acre) if the rajbuhas were made at the Government cost, as was proposed.

On the Western Jumna canal, lands are divided into 1st and 2nd class, the former paying 12 annas per beegah for *Tor*, and 8 annas for *Dál* The latter 6-8 and 5 annas per annum.

But besides the direct return from water-rent, there is an indirect return due to the canal, arising from the increased value of the land, and therefore the increased rent or land-tax that it can afford to pay to Government, the difference in produce between well and canal irrigated land being considerable, while the difference in cost of irrigation under the most favorable circumstances for each, is reckoned as 3 to 1 in favor of the latter. This indirect canal revenue may, and does often, amount to considerably more than the annual value of the water-rent, and though it does not appear in the canal returns, the work should always have credit for it. In the N. W. Provinces it is estimated at Rs. 1-8 per acre, per annum, on the whole area irrigated.

323. Allusion has already been made in a former Chapter to the effective work done by every cubic foot of water in a canal, generally called the irrigating duty per cubic foot. It is evident that by dividing the total annual water-rent received during the year, by the average discharge per second throughout the year, the annual value of each cubic foot of water can be determined.

From the latest returns available, the following table has been compiled:—

Name of Canal	Average discharge per second throughout the year at the head	Area irrigated	Area irrigated per cubic foot of supply	Total water-rent	Value of supply per cubic foot	Water-rent per acre irrigated.	Length of rajbuha open	Area irrigated per mile of rajbuha	Water rate per mile of rajbuha
1864-65.	c. ft.	acres.	acres.	RS.	RS	RS.	miles	acres	RS
Ganges canal, ...	4,026	5,66,517	140	8,95,012	222	1·58	2 140	232	367
Eastern Jumna canal,	1,025	2,25,266	220	3,21,791	314	1·43	602	374	534
1862-63.									
Baree Doab canal, ...	1,450	1,26,016	87	3,08,861	213	2·45	400	315	772
1863-64.									
Western Jumna canal,	1,254	3,51,537	280	3,65,674	292	1·04			

The irrigation in the Ganges and Baree Doab canals is not yet fully developed, though steadily and rapidly increasing on the former. The Eastern Jumna canal returns however may be safely and fairly taken as a guide in estimating others.

The rate of expenditure on well managed canals in good working order may be taken at Rs. 120 per cubic foot, with an extra Rs. 50 for rajbuha repairs, if they are done by Government. The difference between the income and expenditure, is the clear profit per cubic foot of discharge per annum, whence the per centage of return on the original cost of the work can be determined.

Comparing the above figures with those given above, we get—

Average prime cost of a cubic foot of water, per second, of discharge, ...		Rs., 4,200
Average annual value of a cubic foot, say	Rs., 300	
Deduct average annual expenditure on a cubic foot,...	„ 120	„ 180

showing an annual profit of about 4½ per cent.

But the water-rates from which the second item has been deduced are very low, and have since been considerably raised, so that the average annual value per cubic foot, ought to be considerably higher than the above.

And this calculation is from water-rent only, and takes no account of the enhanced value of land; assuming this enhancement, as said above, at Rs. 1-8 per acre annually, and that each cubic foot irrigates 220 acres, then the net returns would be swelled from Rs. 180 to 510, and the return on the capital would be 12 per cent.

324. It is evident however, that the data for the above calculations are exceedingly variable, and canal statistics are too imperfect for them to be considered as anything more than rough guides—as such however they are valuable. The saving in remissions of revenue which are often forced upon Government during seasons of drought, in districts where artificial irrigation does not exist, and the general prosperity of the people, are also items, which although they cannot be exactly reckoned by figures, are of not the less importance on that account, and must be set down as very tangible benefits derived from canals. The value of the crops irrigated by the Ganges canal for last year is estimated at 1½ millions sterling, of which the sugar, cotton, and indigo, valued at upwards of £600,000, are almost entirely due to its influence; and wheat valued at nearly half a million is largely indebted to it.

One other point remains to be noticed in connection with the benefits from Canal Irrigation,—the raising of the surface water in wells owing to the percolation from the canal, whereby the labor and cost of well Irrigation is of course very much lessened; moreover in many of the desert districts where brackish water has alone been found before the construction of the canals, the effect of the water in the latter has been to sweeten the well-water, and make it palatable for drinking.

Against these benefits has sometimes to be set the formation of *jheels* or swamps in low ground, which, however, may generally be reclaimed by proper drainage. A more serious evil is the presence of the saline efflorescence (known locally as *Reh* in the N. W. P.), on some kinds of soil when irrigated* which greatly injures its productive value. On the Western Jumna canal this evil has been the subject of serious consideration, and I believe it is partially developed on the Baree Doab Canal. The salt appears to be in the ground at a certain depth, and to be developed only after being flooded with water—and hitherto no effectual remedy has been devised for it.

Still these are very small and partial sets of against the immense benefits due to Irrigating Canals.

The minor items of Revenue from Irrigation Canals, and which have been named above, need not further be commented upon here.

From the report of the Chief Engineer of Irrigation N. W. P., it appears that the net profit for the year 1864-65, upon the original cost of the Eastern Jumna Canal was 12·85 per cent—and for 1863-64 (the latest returns I can get for the Western Jumna Canal), the profit is 15 per cent, or taking into account the increased land rent due to its influence to 32 per cent. on the original outlay. The above includes the *direct* returns.

As these are the only two canals of any size on which the Irrigation has been at all developed (indeed the Western Jumna Canal is still far from perfect) the above returns are of interest and value—and seem to prove that a good remuneration from such works will in the end accrue to their proprietors, if designed and carried out on proper principles. On the other hand no Engineering Works require so much anxious forethought and scientific design as Canals of Irrigation, as none require more skill in construction as regards both the workmanship and materials employed.

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* This evil however is not the result of canal water only. Well irrigation is often more conducive to its production than canal irrigation.

CHAPTER LV

MADRAS CANALS.

325. THE Madras System of Canal Irrigation, like that of the North Western Provinces, is simply a development of the old native method, improved on scientific principles and carried out in a more permanent manner.

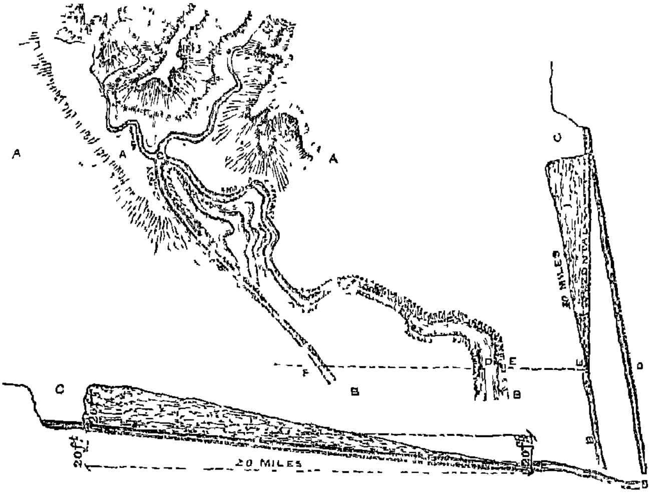
A general outline of the native system may be given in a few words. Channels of supply, proportioned in dimensions to the area of the tract dependent upon them for irrigation, were cut from the river bank, and supplied sometimes with head sluices of masonry, but very often wanting in these necessary works. The levels of the heads were so arranged as to command a full supply in moderate floods, and the water was led to the fields by infinite numbers of smaller channels of distribution. When the level of the river surface was too low for the supply of the channels, the construction of a temporary earthen dam (corumboo), or a permanent masonry dam (anicut) was had recourse to, and the water was thus raised to the requisite height.

Our improvements on this system have consisted in establishing permanent Dams to replace the temporary ones, and in a better alignment of the irrigating channels, which are in fact much the same as those described in the first Chapter as Inundation Canals, with this important difference, however, that by the construction of the Anicut or Weir at the head, the permanency of their supply is ensured.

The general fall of the Deltas, on which the largest works have been constructed, does not exceed 12 inches per mile, from the head down to the sea. The difficulties therefore, that have to be encountered in the Upper Provinces from an excessive fall in the upper part of a Doab, and from the country being cut up by formidable hill torrents, are not met with in these Delta works; and they have the still greater advantage of being continually progressive, both as to cost and revenue; in other words the returns from them are quicker, and perhaps more certain. This arises from the tenure of the land, which is on the Ryotwaree system, being held by the cultivator direct from Government at a yearly rental, instead of on a Permanent Settlement, as in Bengal, or on a 30 years' lease, as in the N. W. Provinces. No water-rent is charged, but a higher rate is gladly paid for irrigated land, and the whole increase of revenue credited to the Irrigation department.

But besides the great works on the Deltas, irrigation is largely carried on in the plains higher up, by numerous supplying channels cut from minor streams, across which anicuts are thrown, and leading to the fields themselves or to tanks, in which the water is stored up for future use.

326. A plain which it is desired to irrigate can hardly be so situated, but that the bed of a neighbouring river is at some part or other of its course relatively higher in level. Supposing a surface AB to slope from A to B at the rate of 2 feet in a mile, and to be traversed by a river CD, the bed of which falls at the same rate, but is throughout 20 feet below its banks, it is evident that the part of the slope which is 10 miles from A towards B will be on the same level as C, and that were a channel CE excavated, with a horizontal bed, water from the river above C would flow along it until it reached E, whence it might be conducted to irrigate the lower portions of the slope EB.



Note.—In the plan, the same letters refer to spots that are on the same level.

In like manner, if the bed of the channel were made to fall one foot per mile, it would at 10 miles be only 10 feet below the country; and at 20 miles, having gained a foot per mile, it would emerge on its surface.

The case is more unfavorable, but still similar, though the country should also slope, as it most frequently does, towards the river, as well as towards the sea. In this case the water to the lands farthest from the river must be brought from a part of the bed nearer to its sources, and the excavations must be deeper: or, as it will often happen, the expense bearing too high a ratio to the attainable advantage, the irrigation must be restricted to those lands which lie nearest to the course of the river, and at the lowest levels.

Channels of irrigation have been taken off rivers such as the Palaur in Arcot, the fall of the bed of which is at the rate of nearly 10 feet in a mile, and its ill defined banks 6 to 8 feet high; as well as from such as the Kistna, which runs with a fall of less than 1 foot per mile, and between steep banks of 35 feet.

It is the relative fall of the river and of the country on its banks, which determines the least length which the channel can have, in order that its bed should emerge above the surface, and its water be brought to use; but when the freshes are of short duration, and channels are led to tanks, it is evidently desirable in order that they should deliver water rapidly, that they should be wide, and the velocity of water in them considerable, although to afford slope to their beds, their length should be extended, and the expense of excavation increased. Six or eight yards may be considered the greatest depth to which irrigating channels have yet been excavated in this Presidency, but the general average is not more than 2 or 3 yards. Great portions of some channels have been formed by throwing up one bank only on the lower side of a slope; and the heads of some river channels, by separating part of the bed of the main stream by means of an artificial bank, protected by river grasses, &c. In some cases, these artificial banks are carried for very considerable distances up the rivers, or obliquely across their sandy beds.

Such banks, termed *Corumboo*, are generally over-topped and carried away by all freshes of more than 1½ yard depth of water. They are temporary expedients or substitutes for permanent dams or anicuts, to turn the early and low freshes of rivers into irrigating or tank channels, and being liable to be partially, and sometimes entirely destroyed by every full fresh, require to be repeatedly repaired, and occasionally reconstructed during every season. They are usually constructed and kept in repair by the proprietors of the lands which they irrigate, without any cost to Government.

327. The word "*Anicut*" is Tamil, and means generally dam or weir. Engineers have generally restricted the use of the term to a dam across a stream, and that of the word "Calingulah" to a work of similar form in the bank, either of a supplying stream or of a tank.

The chief object of Anicuts is to raise the water of the streams they are built across, in order that a portion of it should be diverted into channels leading, as the case may be, directly to the fields or to tanks, in which the water is stored up to be used as required. Some anicuts are, like calingulahs, furnished with dam-stones to sustain temporary banks of mud, &c., and to raise the water in the river beds during the dry season and and the early and low freshes; such temporary embankments being washed away by the freshes. Others are provided with sluices, or have low parts or gaps left in them, seldom exceeding 5 feet each; within which limit, it is not difficult to provide means of closing, such as shutters, &c. By these, the sand is more or less prevented from accumulating to the height of the crown of the dam; and parts of the beds of the rivers, generally inconsiderable however, are thus formed into pools extending towards their sources.

These are in no instance looked upon in the light of tanks. They may, for a trifling period at the very end of the dry season, answer the same purpose, but the irrigation depends in all cases either upon the continual flow of a small quantity of water during the early part of the hot season, or upon tanks generally far away from the river, and which are supplied by channels during the freshes.

Almost all the rivers in the Carnatic, are little more than beds of dry sand during the hot season, and very little water can then be procured from them for the purposes of irrigation. During the monsoons they are more or less full, and it is then only, or at least chiefly, that a portion of their waters is directed by means of anicuts and channels into the adjoining country, to moisten and fertilize the rice and garden lands. During the periodical rains there is generally too much water, and in the hot months none, and the object of all the expedients and works of irrigation is to rectify these evils, by collecting and retaining in tanks or reservoirs, portions of the surplus water of the monsoon, for the irrigation of the country during the dry season.

When the slope of the country is gradual, it is evident that a dam across a river may, by raising the water in its bed, very much diminish the length of an irrigating channel to be led off it, and it might appear that anicuts would on this account be found general in the *lower* parts of the courses of rivers, where the fall is gradual. But this is not the case, because the lower parts of rivers are generally wider, their beds sandy and unfavorable to such buildings, and their banks low. The obstruction of the bed in such localities, would raise the surface of the water in freshes, and render necessary the formation of banks, to prevent the inundation of the country through which the river passes: for, however advantageous such inundations are in the Deltas of the Ganges and Godavery, they are most carefully guarded against on the banks of the Cauvery and Tambrapoorny, where the crops are raised, not by *inundation*, but by a very artificial, and (as far as the science of agriculture is concerned) a very perfect system of *irrigation.*

Anicuts are most generally useful nearer to the sources of streams where they traverse rocky country. In such situations, rocky foundations can generally be obtained, and the work built securely, while, although the fall of country is great, and channels do not need to be very long, yet without anicuts, the difficulty arising from the nature of soil, in such parts generally stony, and which it would be necessary to excavate to a great depth, would be very often absolutely insuperable.

A rocky bed, though a great advantage, and always to be preferred in selecting a site for an anicut, as contributing to reduce the cost and increase the stability of the work, is not however an indispensable requisite. Several anicuts have recently been built with perfect success and at a moderate expense across rivers, the beds of which consist entirely of pure sand to a depth far beyond the foundations of these works. On such occasions, the chief point to be studied, is the formation of a strong and substantial apron beneath the anicut, to break the over-fall of the water, and prevent the foundations being undermined.

Generally, in the wide and flat beds of rivers near their mouth, the scanty supply of water during the dry season is collected and turned into channels by means of the temporary embankments of grass, baskets, sticks and sand, which have already been mentioned by the name corumboo, but there are two modern anicuts in such situations, whose success has since led to the projection of others in similar situations.

328. These are the upper and lower anicuts across the Coleroon, built at the suggestion, and under the superintendence of, Captain (now Major-General Sir) Arthur Cotton, of the Madras Engineers. Both these works have superseded and rendered unnecessary the construction of extensive corumboos; while, unlike corumboos they resist the action of freshes, and assist the irrigation in all states of the river. The upper anicut is built where the Agunda (or whole) Cauvery divides into two branches : the Coleroon, which seeks the sea by a straight course, falling at the rate of about 2 feet per mile ; the smaller but more useful branch (which retains the name of Cauvery) flowing on a more elevated bed ; and, after having in the short distance of 40 miles, gained no less than 15 feet on the level of the bed of the main branch, dividing and subdividing until its ramifications spread over the greater part of the Tanjore District, in irrigating which almost all its water is gradually exhausted. For many years previous to 1836, the Tanjore cultivation had pressed so closely upon the supply of water afforded by the Cauvery, that in seasons falling at all below the average, extensive tracts of valuable land either remained uncultivated, or were subject to the still greater evil of being cultivated in vain. The defect was chiefly attributed to the accumulation of sand in the upper part of the stream near its separation from the Coleroon, and to remove which various expedients were devised and adopted, with partial but only temporary success, and inadequate to the necessities of the case.

At this conjuncture, viz., in 1834, Captain Cotton, then Civil Engineer of the Division, devised the anicut which is built across the Coleroon, about 100 yards below the separation of the two rivers, and by raising the bed of the Coleroon about 6 feet, has, without diminishing, except in a trifling degree, the capacity of its section for the passage of high freshes, rendered available for the supply of the Cauvery and of Tanjore, all the water which even in the driest season, and when most wanted for irrigation, used to pass waste to the sea. The lower anicut was built in the same year, about 70 miles down the same river, and serves to turn the water that accumulates in the intervening part of the river bed, from the drainage of cultivation and the springs that ooze from the sand, into the country on both sides, and irrigates extensive and fertile tracts of land in the Tanjore and South Arcot districts, between the anicut and the sea.

329. Anicuts, as usually constructed, are walls of masonry erected on a solid foundation and carried right across the whole breadth of the river. The material used is either stone throughout, or brick-work covered with cut stone, the foundations usually resting on shallow wells sunk in the sandy bed of the river (unless the site happily offers a rocky foundation), and the superstructure made partly of dry stone and partly of stone set in mortar. The sill of the anicut over which the flood-water pours, is of cut stone set in the best cement. The face of the work may be perpendicular or nearly so; the rear will be made into a long slope, which gives great strength to the work and protects the rear flooring from being injured by the water falling vertically on it. When, however, it is necessary to have a vertical fall on the down-stream side in any portion of the weir, either on account of sluices being fixed there or for any other reason, the flooring is carefully protected by large slabs of cut-stone laid on an unyielding foundation with fine mortar joints. In any case the bed of the river is protected for a considerable distance down-stream from the action of the water at the tail, by a flooring of dry stone of the largest size procurable, and carefully packed by hand. The water will often work holes even in this, which have to be filled up with more stone, and this will often continue for several seasons before the work is safe.

It will thus appear that such a weir requires the expenditure of a very large quantity of material, and that without the presence of an abundance of stone on the spot, its construction as above would not be feasible, or at least would be enormously expensive.

Had such a work to be made of brick, the foundations would have to be much deeper, the body of the work would be of the best pucka masonry, and similar arrangements for the flooring and sides on the down-stream side as have already been described as necessary in the case of canal falls. The shallow foundations of these works are a peculiar feature in Madras Engineering, and a similar practice in bridge building has been already commented on in para. 89. In the case of anicuts, the arrangement is evidently only practicable from the long talus or slope of dry stone given invariably on the down-stream side of the work, which is free to fall in and fill up holes scoured out by the under-current, and is replaced continually by fresh renewals. A similar arrangement to this is the crib-work of boulders provided so carefully on all the Ganges Canal bridges. In the dry season, however, deeper foundations would probably be preferable in order to prevent so much percolation below the weir, and the consequent loss of so much water. But in Madras, unlike Upper India, the crops raised at this season are far less valuable than those grown in the rains, and this difference necessarily produces a difference in the plans of the Engineers. There is also good reason for believing that the coarse sand of the beds of rivers in Southern India is much less disturbed by the action of running water than the fine sandy beds of Upper Indian rivers.

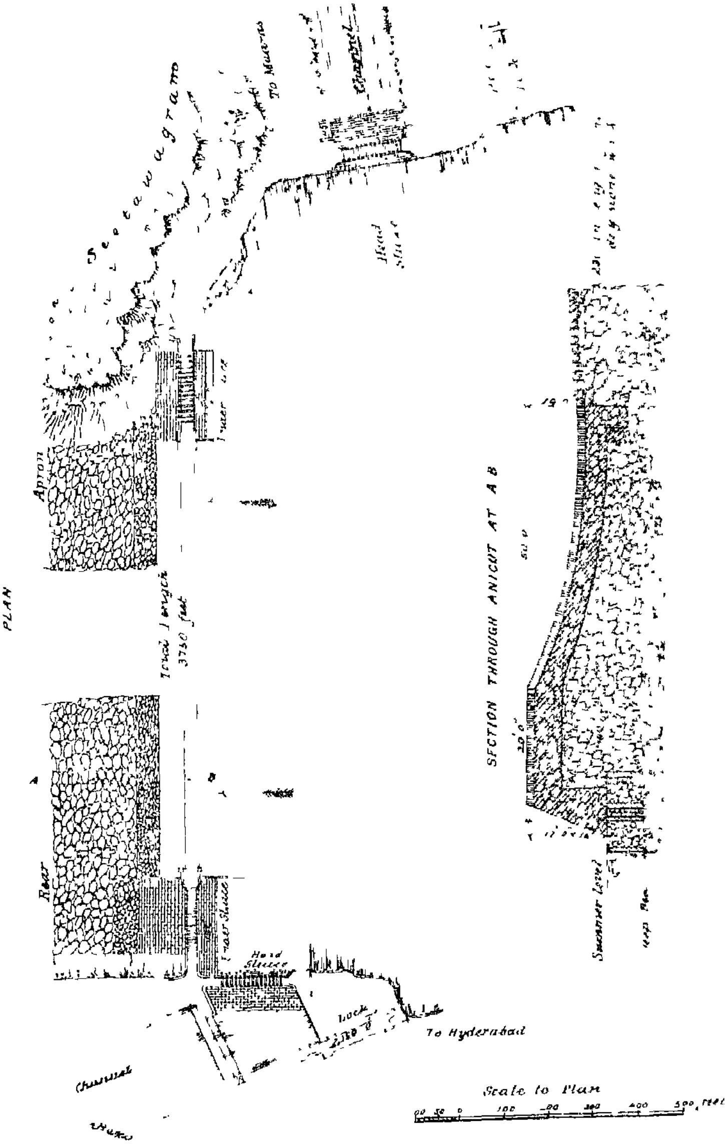
As the water when it arrives at the head of these Deltas is much charged with silt, the effect of this upon the anicut has to be carefully considered. In the earlier works a number of small sluices of about 2 feet in width were provided through which the silt should be scoured, but their size made them quite ineffective, and Colonel Baird Smith has given it as his opinion, that so long as a weir is preferred to an open dam, the elevation of the bed above, by the deposit, of silt, even up to the level of the crown of the weir, must be regarded as an inevitable result and provided for accordingly. Indeed, so long as arrangements can be made to restrain the water within its banks above, and the silting up does not cause inundations, or force the water into a new channel, it will be positively beneficial, as by this raising of the bed, a considerable fall for securing surface irrigation from the canals is obtained. Nature in fact helps in this arrangement; as it has been already remarked that such rivers run on a crest or ridge formed by their own deposits, and thus afford considerable facilities for canal irrigation.

330. The following description of the Kistna anicut is extracted from the author already quoted:—

> Nature has indicated by unmistakeable signs, that the true position for the Kistna dam is at Bezwarah, about 60 miles from the junction of the river with the sea. Here there are two low hills, the last outlying spurs of the high lands to the north Between them the river flows in a channel reduced to a manageable breadth of 1,300 yards, but with a depth of water so variable that no single statement would give a correct view of it—rising as it does, during the monsoons, to between 30 and 40 feet, and sinking during the dry season to, perhaps, 5 or 6. The hills in the neighbourhood of Bezwarah furnish an unlimited supply of stone for building or protective purposes; lime is readily procurable, as are all the other materials required for the work. The position is exactly at the apex of the Delta, and the height is sufficient for purposes of irrigation. Its construction has presented some peculiar difficulties from the fact that the river is concentrated into a single undivided channel between the Bezwarah and Seetunagram Hills. It has, therefore, been necessary to work constantly in water, and the design of the dam has special reference to this necessity. It consists—1st, Of a broad basis of the heaviest stone that could be procured, simply thrown into the river and allowed as it accumulated to assume its own

PLATE LXX

KISTNAH ANICUT



natural slopes. The exact length of this mass of stone is 3,750 feet: its breadth 305 feet; its height in front, 21 feet above the deep bed, and 14 feet above the summer level of the water. It is faced along its entire length by a casing of stone masonry 75 feet in breadth, of which the front curtain wall is 9 feet thick at bottom, 4 at top, and 14 feet high, resting on a double row of foundation wells which fill up the space between the deep bed and summer line levels, being therefore 7 feet in depth. The sill or wasteboard is 20 feet in breadth, and 5 feet in thickness, 4 feet being of masonry and the upper foot of cut stone strongly bound throughout with iron clamps. The tail of the masonry casing is a flat semi-counter arch with a half chord 50 feet in length, and a versed line 10 feet in height, and this portion is terminated by a rear curtain wall running along the entire length of the dam, 8 feet in depth and 3 feet in thickness, embedded in the loose stonework of the main body of the dam. At a distance of 50 feet from the rear wall of the casing, a second line of masonry, somewhat irregular in dimensions, but averaging about 6 feet in thickness and 5 feet in depth, crosses the work from right to left, acting as a retaining bond to the rough stonework at the part most exposed to danger from the action of the current in floods. From this wall to the deep bed of the river the slope is worked out by the aid of rough stonework extended over a distance of 180 feet.

At the right and left extremities of the dam, undersluices are provided for the purpose of scouring out the silt in front of them, and thus keeping an open channel at the heads of the irrigation lines. No under-sluices have been made in the body of the dam, and the filling up of the river-bed in front to the level of the crest of the work has apparently been accepted in this case as an inevitable result. The sluices above-mentioned are two in number, and similar in all respects. They are situated at the extreme limits of the dam, one at each flank, and consist of massive masonry structures founded on wells, in the usual native fashion; each has 15 vents of 6 feet in breadth each, fitted with planks and machinery for opening and closing; the level of the flooring is 3 feet below that of the heads of the irrigation channels, so that when the vents are open there will be a very efficient scour in front of them, and a deep clear channel maintained thereby through the light sandy deposits in front of the dam. The head-sluice of irrigation on the right of the river has fifteen openings, each 6 feet in width, with a clear height for the passage of water (as measured on the plans) of 11½ feet, exclusive of the archway. It may be assumed, however, that an average depth of 10 feet in the channel would represent the full supply of water during the season of irrigation, under the existing arrangements; with the dimensions specified, and a slope of about 12 inches per mile, the discharge would be equal to nearly 3500 cubic feet per second, sufficient for the irrigation of 140,000 acres of rice, promising to the Government in one single district an increase of revenue which may be fairly estimated at not less than two lakhs of rupees, £20,000 per annum, and to the agricultural community a gain of fully three lakhs, or £30,000 during the same time. On the left bank similar arrangements are made by a sluice of the same waterway as above and promising similar favorable results, and from works for which the total estimated outlay on the part of the State is fifteen and half lakhs of rupees, or £150,000, the annual increase of revenue will not fall short of, and may probably, as in similar cases elsewhere, exceed the anticipated amount of four lakhs, £40,000, per annum; and if one lakh, or £10,000, be allowed for expenses of repairs and establishment, the general result will give between 19 and 20 per cent. in direct returns from land alone.

331. Col. Baird Smith thus sums up the points of professional interest which he considers established by the success of the Cauvery works, above described:—

1st. That the waters of large rivers may be distributed between their branches in proportions sufficiently exact for practical purposes, by the use of dams at the points of separation, having their crowns at such heights as experience in each case may prove to be necessary.

2nd. That the influence of such dams, judiciously established on the beds of the rivers, in regulating the currents, in equalizing the distribution of deposits, and in maintaining the permanency of the sections of the beds, may be very beneficial.

3rd. That in rivers with beds of pure sand, and having slopes of 3½ feet per mile, such dams may be constructed and maintained at a moderate expense.

4th. That the elevation of the beds of the rivers above the dams to the full height of the crowns of these works, is an inevitable consequence of their construction, and that no arrangement of under-sluices has, as yet, been effective to prevent this result.

5th. But, that where effective escapes are provided in the banks of irrigating rivers (like the Cauvery), the entire volumes of which are absorbed in irrigation, it is possible to prevent any injurious elevation of the bed by sand deposits.

6th. That in pure sand acted on by the current due to a fall in the river bed of 3½ feet per mile, and exposed further to the action of floods from 12 to 15 feet deep; well foundations, in front and rear, of 6 feet in depth, have been proved by experience to be safe.

7th. That with a vertical fall in rear of the dam from 5 to 7 feet in height, a thickness of 2 feet of brick masonry, and 1 foot of cut stone, with a breadth of from 21 to 24 feet for the apron, have proved sufficient to insure stability, the only further protection required being a mass of rough loose stones about 9 feet in width and 4 in depth. As a rough general rule, it would seem that the masonry apron should have a thickness equal to half, and a breadth between three and four times the vertical height of the bar forming the obstructive part of the dam. The loose stone apron should at first have a breadth equal to one and a half times, and a depth equal to two-thirds the height of the dam. The action at the tail of the work leading to constant additions to the loose stone, soon deranges these proportions, and they are given only as guides in the first instance.

8th. That the main security of the dam depends upon the efficient construction and careful maintenance of the apron.

9th. That in freshes the dam speedily receives the protecting effect of a backwater on the apron; the surface level of the down-stream side being level with the crown of the work when the floods rise to 8 feet above ordinary low water, while beyond that depth the fall over the dam gradually diminishes till in 16 feet floods it has wholly disappeared, and scarcely even a ripple on the surface indicates the existence of the mass of masonry below.

10th. That looking to the cost of the works executed between 1836 and 1853, and the increased area of irrigation due to them, the capital sunk amounts only to Rs. 6-8-0, or about 13*s.* per acre.

11*th.* That after deducting every expense which the irrigation works of the Cauvery have entailed on Government, the net returns may fairly be estimated at not less that 23⅓ per cent. on the invested capital.

332. The works still in progress on the Godavery are similar in principle (though considerably larger) to those already described. The following is a description of the Great Anicut at the head, upon which the whole system depends.

> The Godavery anicut consists of a masonry dam in separate portions, the united length of which is 11,866½ feet, or 3,955½ yards, being very nearly 2¼ miles of river channel blocked up by a solid, substantial, well-protected mass of stone in lime cement, or without it, according to position, having a total breadth of base equal to very nearly 130 feet, and height of crest or sill equal to 12 feet.* The three main objects of the dam—clearance, irrigation and transit—are provided for by three separate sets of works, one on each mainland flank, and one at the head of the central tract. The under-sluices discharge the necessary functions for the first object, the head-sluices those for the second, and the navigable canal and locks those for the third. Along the entire length of the masonry dam is carried a line of cast-iron uprights about 6 inches square, and 8 or 10 feet apart, having grooves on each side for the reception of 2¼ feet of planking, whereby the water can be retained to that height above the sill during the dry season, and a larger volume be thus thrown into the irrigation heads.

The irrigating channels are, or will be, carried along the subsidiary ridges by which the Delta is intersected, and the water is at a sufficiently high level for surface irrigation everywhere.

333. It may seen from what was said in Chapter XLVII., of the difference between the physical peculiarities of Northern and Southern India, why the Madras system is not applicable to the former country. The Inundation Canals already described are, it is true, similar to those employed in Madras, but it would rarely be feasible to construct an anicut to secure to them a perennial supply of water, simply because the enormous expense to be incurred, owing to the great breadth of the river and the absence of any material except brick, would not be compensated for by the small benefit secured. On this point Col. Anderson may be quoted (himself a Madras Officer, and who has had experience of both systems):—

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* The separate masonry portions are connected by earthen embankments, between six or seven thousand feet in length, and protected at the junctions by fully 2500 feet in all, of masonry revetments.

"To make the conditions in the two cases at all similar, it will be necessary to confine ourselves to the 'khadir' lands, or in other words to the tract of country along each of the rivers in the North West Provinces, which is within the inundation limit. But I have explained that the 'khadir' land is generally of insufficient width to furnish room for a first class canal: and, moreover, the fact of the width being inconsiderable implies that the water in the wells is influenced by the proximity of the river; and as the cold weather level of the latter is not above 15 feet below the lip of the channel, and is less than that below the level of the ground at a little distance from it, the cultivator could never be in any straits for want of water. As a rule a great part of the 'khadir' land is inundated during the floods, and the wheat which is sown on the saturated ground on the subsidence of the inundation, requires no further supply of water to bring it to maturity. There are generally some slight showers of rain in the winter, but at the worst, if this aid fails, the people can have as much water as they like at the depth of 10 or 15 feet below the surface of the ground. I may add, that the upper stratum of alluvial soil being only 3 to 6 feet deep, the water permeates the sand underneath it, and will stand at a higher level when the river is in flood than in the dry season, but the change in surface of the water in the wells must be the work of time, and though the river may subside somewhat suddenly in September or October, the water in the wells will not be affected immediately, but will retain a comparatively high level to a much later date.

"Of course the further the 'khadir' land recedes from the river, the more will the advantages above described be absent. The land will not be inundated and the depth of the wells will gradually increase with the distance from the river. It would be difficult to define the limit at which irrigation from wells becomes unremunerative. Much must depend on the rent to be paid, but still more on the aid derived from rain. In the lower parts of the Punjab, the fall of rain is very precarious; still there are always a few showers during the year: and in the winter there are heavy dews which must supply its place in a measure. But taking things as they are, I should say that cultivation languished when the depth of the water in the wells below the surface of the ground exceeded 25 feet. This depth is attained at the distance of 5 or 6 miles from the river; and at the distance of 25 or 30 miles from the river, that is, on the extreme limit of the western khadir of the Sutlej, the depth is 50 or 60 feet, and in some places even more.

"Here then we have at least one tract of khadir land, which would admit of irrigation on an extended scale, and a similar strip of country exists on both sides of the Indus, both in Scinde, and in the provinces to the north of it. I am not aware of there being any other tracts of country along any of the Himalayan rivers, at all events of equal importance, in which the same want of artificial irrigation is experienced.

"The maintenance of the inundation canals is expensive, and the irrigation is partial, and dependent on mechanical aid. It would seem desirable to ascertain if there is the means of making the supply perennial, and of constituting existing canals into branches of larger channels which might be opened at some favorable point higher up the river, and run nearly parallel to it, with the water on as high a level as might be wished.

"The only means of accomplishing this would be by construction of masonry works across the channels, and by extensive flank defences to prevent their being turned. The Madras anicuts have been so successful in positions, where, not many years ago, most Engineers would have anticipated nothing but failure, that one would naturally turn to them as the model to be followed on the rivers under consideration.

"The chief difficulty would be, not to give a work sufficient strength to withstand the floods, or to protect it against a flank movement of the river, but to construct it at all. The Godavery anicut was closed when there was a considerable body of water in the river, though not without great difficulty: but there were stone quarries at no great distance from the work, and the only practical difficulty was to have a sufficiency of boats, wagons, and coolies to bring the stone to the spot. But had there been no quarries, how many brick cubes would have served to make up for the want of them?

"I may remark, that unless the channel is confined within a rocky gorge, so that the width of the stream in the dry weather, is not materially less than in the rains, the simple contraction of the waterway will not be sufficient to ensure a supply to channels on either side. Many of the Indian rivers could not be contracted by artificial works—at places where they pass through alluvial soil or sand, to much under the width of a mile, while in the dry season, the width of the stream might not exceed one quarter of a mile. On the subsidence of the river, the heads of the canals, on one side or the other, would be liable to have a sand or mud-bank, three-quarters of a mile in width between them and the river; which in all probability, it would be physically impossible to cut through in time to prevent the destruction of the crops.

It might be possible by a system of groynes, to obviate the occurrence of the serious inconvenience I have described; but they would be, at best, a very imperfect substitute for a dam, and could do nothing to raise the water, when it might have fallen to an extraordinary low level.

The construction of such a dam across that river must of necessity be a very expensive work. No material but brick would be procurable, unless for coping, grooves, and other work in which stone might be considered essential, and every cubic foot of it would cost about a rupee. Even bricks would cost 14 or 15 rupees a thousand, if not more; and for the enormous quantity that would be required, it would be difficult to get sufficient fuel, at any price."*

334. *Revenue of Madras canals.*—Water-rent is not levied on these canals as in Upper India, but the land irrigated by them is charged at a higher rental, and the increase credited to the Canal Department; another great advantage enjoyed over these canals in these provinces is, that the Madras canals are opened out by degrees, while the Ganges and other canals are nearly completed before any water is thrown into them. In the one case, after an anicut has been completed, and a command over the water in the river thus obtained, the water can be turned to use by the simple excavation of channels in different directions. The depth of excavation at the heads of the main channel may be considerable, but it is generally practicable to excavate them to the capacity required to deliver a supply of water sufficient for the immediate wants of the district, during the period occupied by the construction of the anicut, which will probably not exceed 3 years. Sluices and other masonry works will be required also, but on some if not all of the projected lines of channel, their progress will keep pace with that of the anicut; and there are generally existing channels,—natural or artificial,—which may be used temporarily, if not permanently, to distribute the water in different directions.

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* For the tract above described a project for a dam to secure a perennial supply to the upper Sutlej Canals was prepared and sent to Government some years ago. Nothing has yet been done however It was suggested by Col. Dyas, then Director of Punjab Canals, that such a dam might advantageously be combined with the Railway Bridge, which was then projected in that neighbourhood.

Further, in every part of the Madras Presidency, there are a number of rain-fed tanks, the revenue derived from which may be liable to undergo extraordinary fluctuations, owing to the uncertainty and insufficiency of the supply. The cultivation then becomes a lottery; it may be profitable or it may not; but the cultivators, though they may be ready to run the risk of losing a portion of their crops, will be obliged to refrain from cultivating all the land under their tanks, though if they could secure a good season, they would be only too glad to do it. The addition of the water supplied by means of the anicut channels to such tanks, would have the immediate effect of securing the revenue and of giving confidence to the people.

Even with an expenditure of 20 lakhs of rupees, which is more than would be required to bring an anicut and channels on a large scale, into operation, it will be readily understood that an increase of revenue sufficient to constitute them remunerative works, or a return of 5 per cent. might be realized almost in the very first year, during which a supply of water is provided. Direct irrigation by means of small channels would be carried forward at the same time; and as the demand for water increases, there is comparatively little to be done, beyond increasing the capacity of the main channels for a few miles from the heads.

Thus the Delta projects in the Madras Presidency provide in the first instance for the supply of water sufficient to place existing cultivation in a state of security, and for a moderate extension of irrigation to new land; but they admit, of expansion, until they comprehend the whole of the country which can be brought within command of the water. This system must be considered to be practically a very perfect one.

CHAPTER LVI.

IRRIGATION TANKS.

335. A TANK for Irrigation is formed by an embankment thrown across a line of Drainage so as to collect the water on the upper side, which is then drawn off for Irrigation purposes by means of sluices and channels.

Tanks are of several kinds. 1. Where a bund is thrown across the gorge of a mountain pass which is the bed of a torrent thus forming a lake enclosed by the rocky sides of the pass.

2. Where a natural hollow in the ground outside the hills is made into an artificial lake by closing up all places where the water can make its exit; such a hollow may be a very small or may be a large natural basin drained by a stream or nullah; and the supply for such tanks may depend entirely on local rain, or on streams swollen by rain in the hills above. Or, as is often the case, the tank may be filled by a cut from a neighbouring stream, not running through it.

3. Where artificial side walls are required as well as the front wall, to enclose the water—in consequence of there being no natural hollow but merely a continuous slope of the ground in one direction.

It is evident, however, that these three kinds are merely modifications of each other, depending on similar principles for their construction, and which may be treated of collectively.

In designing a tank when the source of supply has once been ascertained, the first point to be determined is the position of the bund by which the tank will be formed. Other things being equal, it is evident that the narrowest part of the gorge or hollow should be chosen so that the length of the embankment may be as short as possible—and in most cases this will be found to be the best site. But it is also to be looked to that this bund shall hold up the greatest quantity of water possible, and this may in some cases modify the actual site of the embankment. It is evident that the amount of water so held up will depend on the area covered by the water and its depth. This depth again will depend on the height of the embankment and the slope of the bed of the tank—for the water can nowhere rise higher than the lowest part of the top of the embankment (natural or artificial) which dams it up, but will then, if the supply be continuous, escape at that point. Sometimes, therefore, it will be found that a bund at some other spot than the narrowest may give a larger area or greater depth above, so as to hold up such an additional quantity of water as will amply repay the cost of the increased length of the bund.

Other points to be taken into consideration in selecting a site for an embankment are, the relative level and position of land to be irrigated, the quality of soil for foundations, and the proximity of stone and lime, fuel and water, for the supply of the works when in progress.

Briefly, the indications most favorable to the construction of a tank-embankment may be thus enumerated:—1st, A channel bringing down an ample supply of water; 2nd, For the bed of the tank, a broad expanse of nearly level land in front of the embankment, having a slight dip towards the latter; 3rd, That the land to the rear be of greater extent than the bed, and slightly lower in its level, in order that every portion of it may be irrigated through masonry sluices constructed in the embankment, and communicating with earthen channels leading to each field; 4th, A rocky foundation at little depth from the surface; 5th, That water be procurable from the bed of the water-course, or from a well, for the use of the work and workpeople; 6th, That stone, lime, and fuel be within reasonable distance.

It will rarely happen that all these advantages are offered at one locality. The main object of the tank, it is to be recollected is the irrigation of the land to its rear. A careful survey of the proposed site should be made, including the levels of the intended dam, and of the land to its front and rear. The elevation of the embankment, and the area of the bed to be submerged, may then be adjusted and determined, and an opinion as to the irrigative powers of the tank, in reference to its depth and expense, may be formed. The expense of the work is then to be contrasted with the probable return from the irrigation of the land in rear, from the growth of luxuriant crops in the bed after the withdrawal of the water, and from the more indirect benefit arising from the multiplication of wells supplied by filtration from the tank.

336. It next becomes necessary to determine in what way the surplus water that may be thrown into the tank shall escape. If there is perfect control over the stream by which the tank is fed, the water may be turned off when the latter is full, by means of a sluice at the head. This, however, will not often be practicable and in any case an escape must be provided from the tank itself for the surplus water: This may be allowed an exit in two ways; either by the bund itself or by a side channel, arranged so that the surplus water shall flow down it as soon as it comes nearly on a level with the top of the embankment. If such a channel can be provided at a moderate expense it is always the preferable method, as there is then no danger to the bund from the shock of water falling over it—nor of silt or boulders accumulating in the tank, nor of the Irrigation channels and sluices being injured. But in many cases, especially where the tank is formed inside the hills, the expense of cutting such a side channel would be too great, and the only passage for the side water must be by the bund itself. To effect this, flood-gates must either be provided, or the water must pass over the whole or part of the bund. In peculiar cases the former method may be allowed, but as a general rule, the latter method is preferable, as being self-acting. If the bund is of no great length and can be made of solid masonry throughout, then the whole of it can be arranged as an overfall. If so large an escape is not required, and the embankment is of earth for the greater portion of its length, then a portion of the bund must be built of masonry (the top being two or three feet lower than that of the earthen embankment), and will serve as an overfall or waste weir.

337. Such are the general principles of these works—we may now enquire further into the details of their construction.

The thickness of the embankment must of course depend on the nature of the material, as well as on its height and the violence of the stream that has to be arrested. In damming up a hill torrent, boulders will generally be found in sufficient plenty to yield abundance of lime and stone, and if fuel is cheap and water at hand it would be better to make the whole bund of pucka boulder masonry. If not, then the portion forming the overfall must at any rate be so constructed, and the remainder may be made of dry boulders with a long slope on each side and a thin pucka wall in the centre to prevent leakage. The thickness should of course decrease from the bottom to the top, and that portion over which the water is to pass, especially if it is to be of any great height, should be raised, bit by bit, in successive seasons, and the water be allowed to flow over it freely. It will thus have time to consolidate and its strength be satisfactorily tested. The foundations should be carried down to rock if possible—or at least to firm soil. If this is not found at a moderate depth an artificial foundation of concrete or rubble masonry may be formed. The superstructure should be carried into the side rocks to prevent their being turned. The shape of the waste-weir may be perpendicular on the water side with a long slope behind for the water to flow over, and the flooring protected in the usual manner. Additional strength is sometimes given to such massive embankments by throwing out bastions, at intervals, on the water side. One or two of these can be made hollow to contain the sluices which can be worked from the top, and spiral steps may be made inside to descend into the water. Where the supplying water is less violent and in the case of tanks outside the hills, such extraordinary precautions and solidity of workmanship are of course not requisite. Boulders, too will be scarce, or perhaps wanting altogether,—so that earth, bricks, and perhaps brushwood and piles, will have to be the materials employed. The earthen embankment must of course be made very massive, and if it can be protected from the action of the water by a thin wall of pucka brick masonry or dry stone it will be as well. If not, it should be well turfed or defended with piling and wattling. Of course no part of the earthen embankment can be used as an overfall, but if there is no separate escape for the surplus water, a portion of the embankment itself must be made of masonry to act as an overfall.

338. *Madras tanks.*—The banks of the generality of tanks in Madras seldom exceed 5 yards in height. Many of them are formed of earth only, in a few instances carefully turfed; while some of the larger works and, in countries where stone is abundant, many of the smaller banks also, are protected by loose blocks of rough stone laid on the inner sloping surface, or disposed in the form of a nearly upright revetment, without mortar or cement. The object of these rough stone facings is not so much to support the earthwork, as to protect it from the action of the waves during stormy weather, and from damage by the monsoon rains.

Many tanks are often formed in the same valley, the bed of one beginning where the cultivation under that above it ceases. In consequence of this, the breaching of one tank often leads, by the sudden influx of its waters to the bursting in succession of those below it. This is more particularly the case, when heavy and sudden rains succeed seasons of drought during which, the earth of which the tank banks are composed, loses its tenacity and is soon saturated by water. Another, and the general cause of the breaching of tanks is the neglected state of their banks, which are not in all parts sufficiently raised above the surface of the water in them. High winds exciting waves in the tank, throw the spray over the lowest parts of the banks, which are thus gradually worn away, until at last the water overtops them, and a breach ensues.

In Madras, the waste weirs above described, are known by the name *Calingulah*, a Tamil word of originally much wider import. Along the upper surface of these, a row of upright stones two to four feet apart, and from two to eight feet high are generally inserted. The intervals between these stones are filled up with earth, straw, and rubbish, to increase the capacity of the tank when the rains are moderate; but when the supply of water is too great, and the tank is in danger of being breached, the interstices are cleared, to allow a larger quantity of water to escape, the rapidity of the outflow being increased by the additional vent thus afforded. The damstones are made of such height, that the top of the temporary bank raised between them is nearly on the highest level to which water can rise in the tank without endangering its bank. In some tanks, the excess of water flows out from vents pierced at a low level in masonry walls similarly placed. These vents are closed by vertical planks, inserted side by side, or by shutters. Works of this description, termed *surplus sluices*, allowing the water to flow out with greater rapidity, are of smaller dimensions, and less expensive than calingulahs. They have also the very great advantage of permitting the escape of mud and sand from the bed of the tank; by the accumulation of which all such works are otherwise liable, in the course of time, to be filled up and rendered useless. Vents to be closed by planks or shutters have frequently been constructed in the lower part of the body of calingulahs. But the common calingulah is the usual way of allowing the surplus water of tanks to escape.

339. The velocity of water issuing from an opening such as a calingulah depends upon the height of the surface of the water escaping above the bottom of that opening, and is found by multiplying the square root of that depth or height by 5, and the height being in feet, the velocity will give the feet per second; thus the height being $4\frac{1}{2}$ feet, the velocity will be $5\sqrt{\frac{9}{2}} = 15\sqrt{\frac{1}{2}}$: this multiplied by the product of the height and length, will give the discharge. Knowing therefore the quantity of water that can enter the channel or tank in an hour, the length of calingulah is easily found : thus, it is found that for the extreme fall of rain on only one square mile, a calingulah of 120 feet is required, supposing the water flowing out to be of the usual depth, that is $4\frac{1}{2}$ feet, which is about the average height of calingulah damstones in moderate sized tanks. Were the depth to be greater, the discharge for the same length would be increased, and in a greater proportion, viz., that of the square root of the cube. Thus if the depth were multiplied by 2, the discharge for the same length would have to be multiplied by $\sqrt{8}$, and so for an equal discharge. A depth of 9 feet of water would allow of the length of the calingulah being reduced to a little more than $\frac{1}{3}$ of the length required when the depth was only $4\frac{1}{2}$ feet: so that if a tank bank be so high that it will be safe when 9 feet of water goes over the calingulah, 40 feet will be sufficient for every square mile of drainage. But this is an enormous length; it is not unusual for a tank to receive the drainage of a country from several miles around; and if 30 square miles or a quarter of a circle of 13 miles radius drained into a tank, by this rule it would require no less length of calingulah than 1,200 yards in the former case, and 400 in the latter, while there are no tanks having calingulahs approaching these dimensions.

We must therefore inquire into other parts of this important question; and in the first place, we have hitherto proceeded upon two extreme suppositions which can rarely occur together, viz., 1st, That the tank is full before the heavy fall of rain commences; and 2ndly, That 5 inches of rainfall in one hour, or at the same rate as records has shown it to have fallen in 12 minutes only. The length of calingulah necessary would have to be reduced in proportion as the fall of rain is less rapid; and if 120 feet be required for 5 inches an hour, 60 will suffice for $2\frac{1}{2}$ in the same period; or if the water can for a short time be 9 feet above the floor of the calingulah, 40 feet per square mile will do for 5 inches, and 20 feet for $2\frac{1}{2}$ inches per hour. With regard to the first supposition, it is most likely that the tank will not be full when the heavy rain occurs; and in this case the greatest part of the water would be retained in the tank; thus if the bed of a tank contain 5 square miles, and it receives the drainage of 20 square miles (the total fall of rain not exceeding 50 inches in a year), the tank would not overflow if capable of containing 4 times 50 inches, or 16 feet 8 inches over its whole surface; or if the bed of a tank be in any proportion to its drainage, water will not flow out until the number of inches of rain fallen bears the same proportion to the average depth. It is evident, therefore, that the proportion that the tank bears to the surface of the land which drains into it, must also be taken into consideration, and the dimensions of the calingulah regulated by all the circumstances which effect the supply of the tank and the quantity of surplus water. To most large tanks the water is brought from rivers by channels, and the quantity of supply may (in that case) be regulated by a head sluice.

One of the largest calingulahs in Madras is that of the Carangooly tank, in the Chingleput district, and is of the form and dimensions of the annexed plan: it was built, by General Sir J. L. Caldwell, of the Madras Engineers, many years ago.

340. *Sluices of Irrigation.*—Consist of long tunnels of cemented brick or stone, arched or covered with flat stones, passing through the banks of tanks, and on a level with the bed of the tank; furnished at the extremity, inside the tank, with a contrivance for regulating the quantity of water that flows to the fields, and at the other end with a cistern or basin, the walls of which are pierced with holes at different levels, through which water running to the branch channels is carried to fields at various elevations. The sluices in large tanks have sometimes cisterns at the inner end also, the object of which is to prevent the accumulation of mud at the head of the sluice.

The ordinary contrivance at the head of the sluice, known by the name of *payal*, consists in a vertical door (often merely a block of stone) which is removed to allow water to flow, only when the tank is nearly empty, and in a portion of the covering (which is of stone) being pierced with a conical hole, in which a conical block of wood attached to a long bamboo, is moved upwards or downwards from a frame of two large upright stones and two or three placed transversely for the sluice man to stand on. These latter have holes in them through which the bamboo is lifted or lowered. The orifice through which the water issues is blocked by this description of stopple, or opened to any desirable extent according to the demand for water.

Irrigation by tanks is often combined with that by rivers, the water from the rivers being brought into tanks that are favorably situated, by means of channels cut through the river bank and intervening ground.

341. The following description of the Mysore tanks by Captain (now Major-General) Green, will be found interesting :—

" *Tanks.*—There are upwards of 20,000 tanks in the returns, the bunds of which are

CARANGOOLY CALINGULAH -

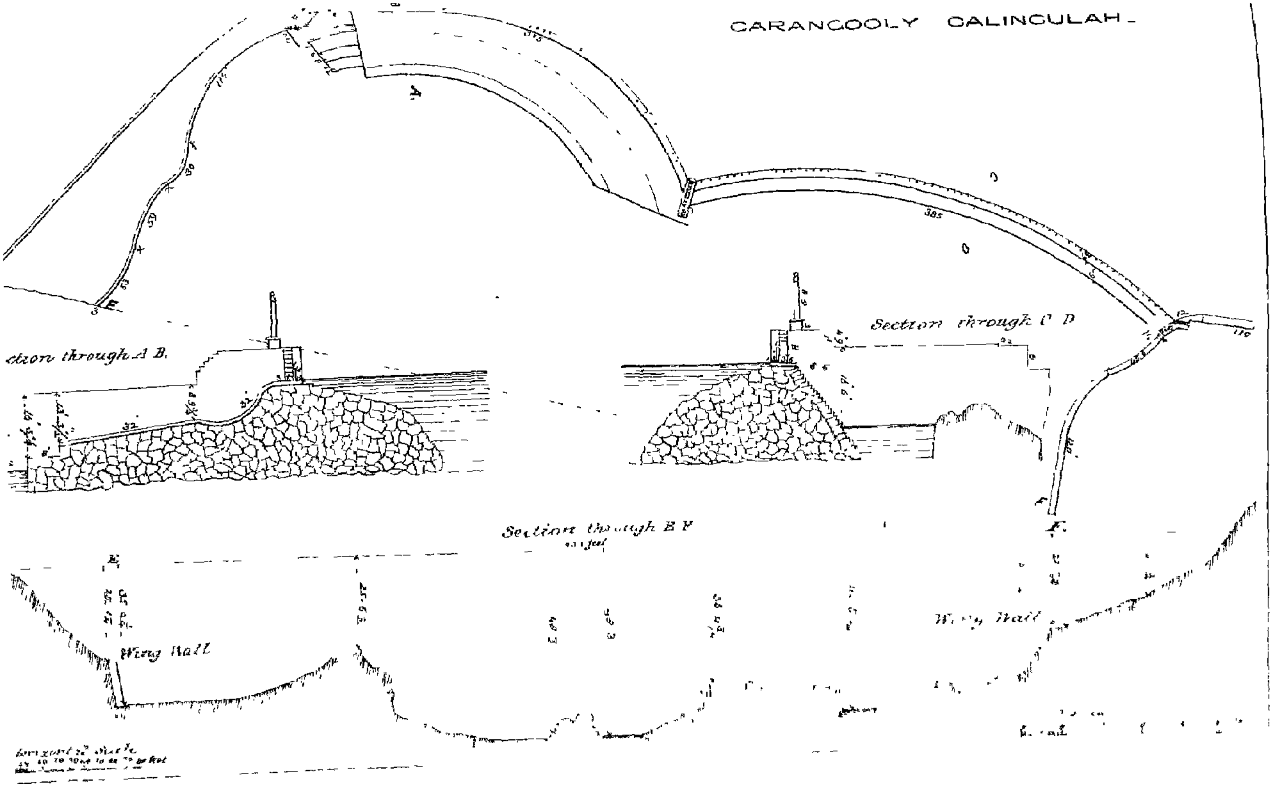
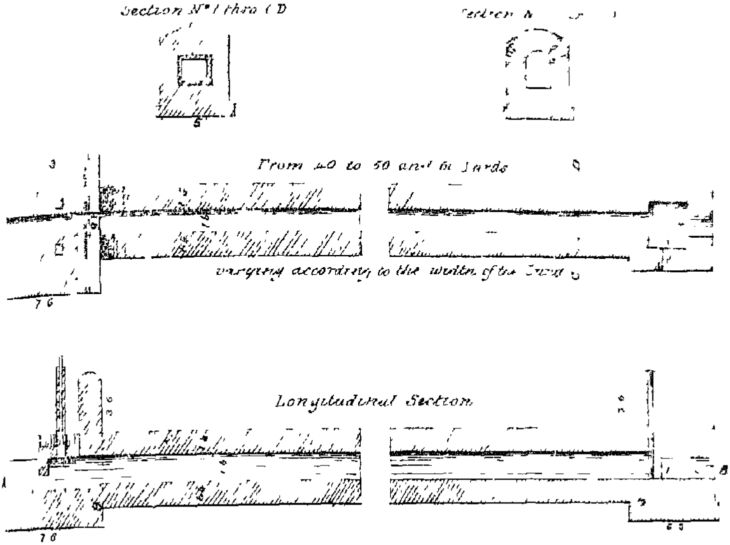


PLATE LXXI.

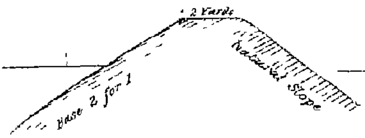
IRRIGATION TANKS

Plan of a Sluice for large Tanks

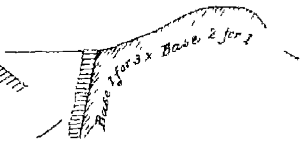

Section No. 1 thro C D
5
Section N
From 40 to 50 and 60 Yards
varying according to the width of the Tank
7 6
Longitudinal Section
3 6
7 6
6 3
A
B

SECTIONS OF TANK BUNDS

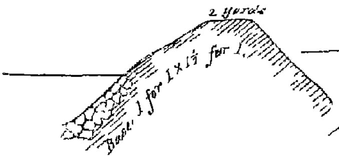
Turf



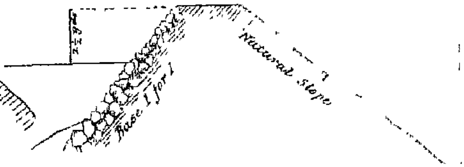
Turf and Quarried Stone



Turf and Stone



Loose Stone



of every variety of length from a quarter of a mile to 1½ miles. They are with very few exceptions, faced with a rough stone revetment, having a batter of about one horizontal in two vertical; the stone facing averages from a yard, to half a yard in thickness, and is backed with loose rubble stones, which are together of a thickness equal to that of the large stones in front. Occasionally a lighter description of revetment retains the rear slope of the bund. The breadth of the earthwork is proportioned to its height, which is greatest in the centre of its length. An ordinary bund is about 12 feet broad at top, 60 feet at bottom, and 18 feet high; there are many in every Talook, however, which exceed the above section.

" *Sluices.*—Each tank is provided with from one to two, and sometimes three sluices, by which the water can be let out to the fields at pleasure. Their position is generally on a level with that of the bed of the tank, but if any portion of the lands to be irrigated be above that level, one or more of the sluices is placed at a corresponding height. A tank sluice is a large, substantial and not unfrequently an expensive work; it consists of a 2 yard square brick or stone cistern one yard high, to keep off the sand at the front of the bund, with one or more valves, or plug-holes in a stone at the bottom, from 6 inches to a foot in diameter. The valve is attached to a pole so long, that the top shall never be covered with the water in the tank. It is held in an upright position by 2 or 4 vertical stone pillars from 9 inches to ½ a yard square, to which horizontal stones are attached, one at top and another midway, down through a hole in the centre of which the valve rod works, having a stout chain and pin to uphold it when necessary, and to regulate the discharge; the pressure of the water upon the top of the valve keeps it sufficiently tight when lowered into the valve hole to prevent the escape of the water. At the rear of the bund another cistern of about the same dimensions and usually of brick in chunam is built, three sides of which are furnished with square openings, and shutters to admit of the water being turned off in the required direction. The two cisterns are connected with a tunnel, the length of which depends upon the cross section of the bund through which it is laid, and is generally from 10 to 30 or 40 yards. The vent throughout the tunnel, for the passage of the water, is about 2½ feet high and 2 feet broad. These dimensions are adopted to permit of a man going in to clear away obstructions, and to examine the state of the tunnel occasionally, should anything appear to have gone wrong. The cross section of a tunnel is like that of a massive barrel-brick-drain, but the vent is generally rectangular and cased with granite slabs about 6 to 9 inches thick.

" *Codies.*—In addition to the sluices each tank is provided with from 1 to 4 open masonry outlets, called codies, the gorges of which vary from 10 to 100 yards in width, and by which the surplus water of the tank escapes to other tanks below. As the rush of water over the codies would wash away any but a strong description of work, by which it was confined in its passage from the tank, the codies are necessarily made very substantial with the largest sized rough stones procurable in the neighbourhood, those of the large tanks rivalling the smaller anicuts on the rivers in the massiveness with which they are constructed, and the brick retaining walls with which they are frequently protected. Codies are generally of a square figure covering as much ground lengthways, as in their width. The front, which breasts the water consists of a solid rough stone wall from 1 to 2 or 3 yards deep, according to the quality of the soil, and of proportionate thickness. It is furnished with dam-stones, which project a yard and a half, and are let firmly into the top of the wall at 1 yard intervals. The addition of some sticks, straw, and turf placed in front of these vertical stones makes a temporary dam, by which the ryots are enabled, after the burst of the monsoon is over, to retain the water in the tank at a level about two feet higher than they otherwise could have done, and to secure the water for a so much larger period.

" The sides of a cody are protected by wing walls 1 to 2 yards high, of rough stone, or brickwork which, contract or approach one another at the ends of the gorge wall, and widen out above and below forming, as it were, the sides of the funnel of discharge.

" The stones on the lower of the gorge wall, are usually laid over suitable foundation in the form of a sloping apron, from its top to the bottom of the nullah below, by which the force of the water is broken; in cases, however, where it is found difficult to render this (the ancient mode of building codies) permanent, recourse has been had to disposing of the apron stones like a flat pavement at the foot of the gorge wall (whatever be the height of the latter) taking care to have a very solid iron clamped platform of cut stones for the water to cascade upon. Its force is there expended, and it flows gently away from the foot of the gorge wall without having the power to do any mischief; this plan is found most effectual, and has never failed wherever it has been tried.

" The level of the top of the cody, whether of the permanent masonry, or of the low temporary dam now occasionally put above it, is the gauge of the powers of capacity of the tank; above that, the cody is always open and acts as the safety valve of the tank.

" In the nullah, immediately below a cody, is sometimes built another work of rough stone like the cody, and equally large, but which so applied is termed a " cuttay." Taken off, from above the latter, is a channel of irrigation. This is a very good arrangement, when the levels are favorable. The cody retains the water in the tank at its highest safe level; the cuttay below appropriates the surplus water, which the cody has discharged, and which but for such cuttay would be lost. Pouring over the cody in a thin sheet of perhaps a few inches only in depth, the sectional area of the water is fully sufficient to supply an ordinary tank channel of irrigation, and when it ceases, recourse is had to the sluices in the bund which are then opened. As the surplus water for 10 or 15 days annually is discharged in a great volume over the codies, the cuttays below are then exposed to a great shock from the impulse thereof, and require to be substantially constructed.

" As the alluvial deposit, year after year accumulating, gradually raises the beds of tanks, they would in process of time become useless were not the alternative adopted from time to time of adding to the height of the bunds, which of course involves an enlargement of the cross section generally, as well as the raising of the codies and the construction of new sluices at higher levels than the former ones occupied, when the sand has eventually choked them up.

" Thus, even if no breaches occur, there is a constant yearly increased demand for tank work, and several of the bunds have attained height in the effort to keep them sufficiently above the surface of the water. The upper part or roadways of several bunds in each of the four Divisions, are on a level with the tops of the cocoanut, and even of the more lofty areca, trees in the gardens immediately below them.

The same resource is had recourse to in discharging the sand from the tank beds, that is adopted for the ejection of that carried into the channels of irrigation from the rivers. But a different season is selected; instead of the close of the monsoon, its commencement is taken, and no sooner is it seen that the monsoon has set in, than the ryots range themselves about the sluice head in the tank, which is at this time shallow, and stir up and agitate the bed, till, reduced to a semi-liquid state, it runs off through the sluice with the water. This, like the opening of the nullah under-sluice, is however but a partial remedy. It is less expensive to raise the bund than to carry away the sand by hand.

"Most tanks receive their supply from the high ground in the neighbourhood, and irrigate paddy fields or gardens immediately below them; but there are exceptions to this, as numerous tanks are partly supplied by channels winding round more remote hills, and which catch all the rain water flowing down their sides and convey it into the tank. Water-courses or nullahs which are called into existence during a local fall of rain, are also dammed up, and their contents in like manner appropriated to the benefit of tanks. A single tank may possess several feeders of this kind, all of which require to be kept in repair.

"In like manner the fields to be irrigated are occasionally at a distance from the tank, and have channels of irrigation therefrom, including their windings, of from 2 to 30 miles long, and upon the preservation of all of which in proper order, depends the success of the crops. The water of the Soolikerray lake irrigates land at a distance of 30 miles. Other reservoirs of water, not connected with the irrigation, but such as public wells, bowries, cuttays and so forth, which are required for the use of the inhabitants and their cattle, have been extensively restored in every Talook in the country; and the consideration of the Government in directing these improvements of works so essential to the health and comfort of the community, is rightly appreciated and gratefully acknowledged.

342. It is calculated in Madras that a cubic yard of water is required for every square yard of land having to be irrigated constantly through the year. This appears to be a large amount, but in the absence of more certain data it may be used in estimating the probable return of a tank.

Rice land requires to be covered throughout with water to a depth of half an inch; seventy two days are calculated as the time required by the land to be covered with water; therefore for a *cawnie* of land, (6,400 superficial yards,) 6,400 cubic yards of water should be stored for every cawnie which is to be watered.

A channel should supply $\frac{6400}{72} = 88\frac{8}{9}$ cubic yards per diem, or $3\frac{19}{27}$ cubic yards per hour for every cawnie to be watered.

It is usual, in calculating the water required for a cawnie, to allow 10,000 yards, which allows for evaporation, wastage, absorption, &c.

$88\frac{8}{9}$ cubic yards $=$ 2,400 cubic feet per diem $=$ 100 cubic feet per hour, and requires a vent of $\frac{1}{10}$ of a square foot at the velocity of 1,000 feet an hour; at one mile an hour, it requires $\frac{10}{528}$ of a square foot.

For 440 cawnies of rice land, equal to one square mile, water running at the rate of one mile an hour will require a vent of $\frac{4400}{528} = 8{\cdot}3$ square feet.

Not much attention, as a general rule within certain limits, appears to be given to the size of orifices for the discharge of water for irrigating land under tanks. The sluices which are pretty numerous, because some lands are higher than others, and again belong to different villages, are furnished with conical shaped vent holes in front, cut in stone, with some little regard to the quantity required: these are furnished with conical plugs; and a little practice enables the person whose business it is to distribute the water, to judge what amount of opening is required.

343. The tank system of irrigation so common in lower India is comparatively rare in the Upper Provinces. Indeed the only districts where it has been carried out on a great scale, the principle having been applied by the Natives from time immemorial, are those of Mairwara and Ajmere, where Colonel Dixon's energetic attention to the subject produced most successful results.

The districts that lie at the foot of the Hills on the E. N E. and W. of the Punjab would, however, seem to be peculiarly adapted for it. Rain is scarce, the hill streams are numerous, and the soil in general of good quality. A system therefore by which the temporary supply of water from occasional rain might be stored up for future use, is one that is deserving of serious attention.

In the Punjab, the tank would sometimes be filled twice a year—about the months of February and July—and would irrigate both crops. In other parts, especially on the Western frontier, where very little rain falls in the cold weather, it would often happen that the water would be available for the *Khureef* only. The bed of the tank might in this case be sowed when dry in the autumn for the spring crop—as the soil would be wet and probably rich from the silt deposited in it.

344. On the Western frontier of the Punjab, where rain is excessively scarce, and the ground near the Hills at so high a level that it is impossible to irrigate it either from Wells or Canals,—the natives are very ingenious in turning the water that occasionally comes down the hill nullahs to good account. The dry bed of the stream is taken possession of, and dams of earth and brushwood thrown across from bank to bank at different favorable points. When the water comes down, its level is thus raised against these bunds and it is skilfully directed down the secondary channels, natural or artificial, whose mouths are just above the dam, and which in their turn are bunded. By a similar method the water is turned down still smaller channels until finally it is thrown on the fields, which are bunded all round to retain it. When the bunds of the main stream are over-topped and carried away, which usually happens in a very short time, those lower down the stream get their share of water—and so skilful is the organization that although these floods last but a very few hours the water is distributed in the above manner by hundreds of weirs and minor channels over a large extent of cultivation—and with, generally speaking, remarkably few disputes.

The great defect of the system is that if only a small quantity of water comes down, the bunds lower down the stream, go without; if a large quantity comes down the violence of the torrent is so great that the earthen bunds are carried away in succession too rapidly, and three-fourths of the quantity is wasted. Moreover the cultivation is precarious in the last degree as rain is so very rare. If masonry dams or weirs could be substituted for these earthen bunds, it is evident that the water would be under far better control than at present, and moreover could be stored up for future use in the bed of the nullah above the weirs. By a proper system scarcely any would be lost. Suppose for example a nullah some fifteen feet deep with a fall in the bed of twenty feet per mile—it is evident that, if dams be constructed from bank to bank at every three-quarters of a mile, the surplus water passing over their tops in succession, a series of still water canals would be formed whence the water could be drawn by means of channels or the Persian wheel. If the beds of these nullahs were too shifting and shallow for this, then the waste water could be thrown by means of small side cuts into artificial earthen tanks. By a proper application of these two methods, there is little doubt that a great extent of country now lying barren could be brought under irrigation.

In the construction of such weirs, the same rules apply as have already been stated with regard to tank dams—wherever the banks are at all liable to be cut away, great precautions are necessary to prevent the weir being turned. The masonry must be carried well into the banks on both sides and water walls added for some distance both up and down-stream.

345. The following description is from Colonel Baird Smith's work:—

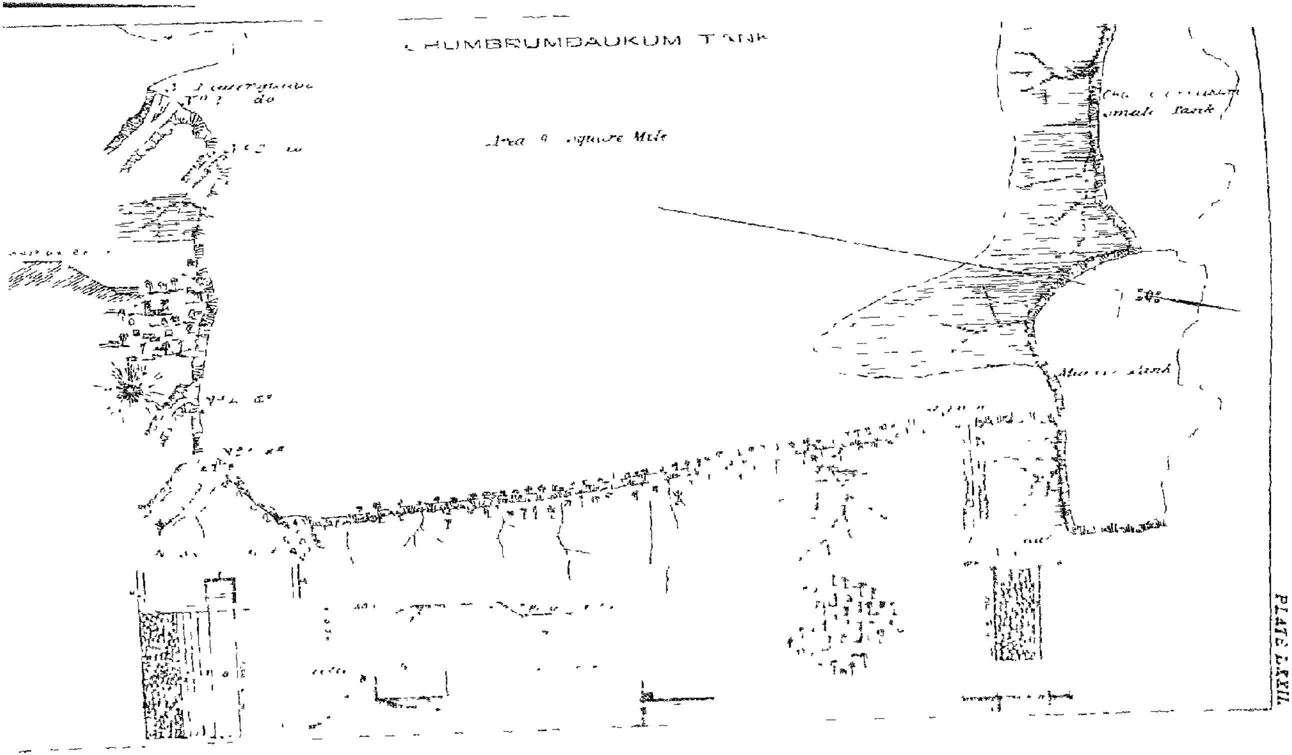
The tank which bears the rather formidable name of Chumbrumbaukum is one of the finest in the Madras Presidency. It is picturesquely situated in the vicinity of bold hilly ground, and looks like a natural lake in a position where such a sheet of water might very readily be looked for. Beyond furnishing the water and the site, however, nature has had very little to do with its creation. It is purely artificial, and its supply is retained by an embankment 3 miles 5 furlongs 20 yards in length, ranging from 9 to no less than 28 feet in thickness, and from 16 to 26 feet in height. Its area is 9¼ square miles, and its volume may be estimated at 3,000 millions of cubic feet of water. It maintains a sheet of rice cultivation, nearly 10,000 acres in extent, yielding to Government an annual revenue of rather more than 50,000 rupees, and the cost of improving its various works, and keeping them in efficient repair has averaged, during the last 20 years, about 7 per cent. on the revenue derived from it. Its apparatus for distribution consists of 10 irrigation sluices. Its safety during floods is insured by the action of six waste weirs or calingulas, giving in the aggregate a breadth of escape channel of 676 feet, with a depth below the crest of the embankment ranging from 6 to 13 feet according to position. Through this area an enormous mass of water can escape, and as the supply is dependent almost exclusively on natural rainfall and merely local drainage, the protective provision has proved adequate, and breaches have been very rare.

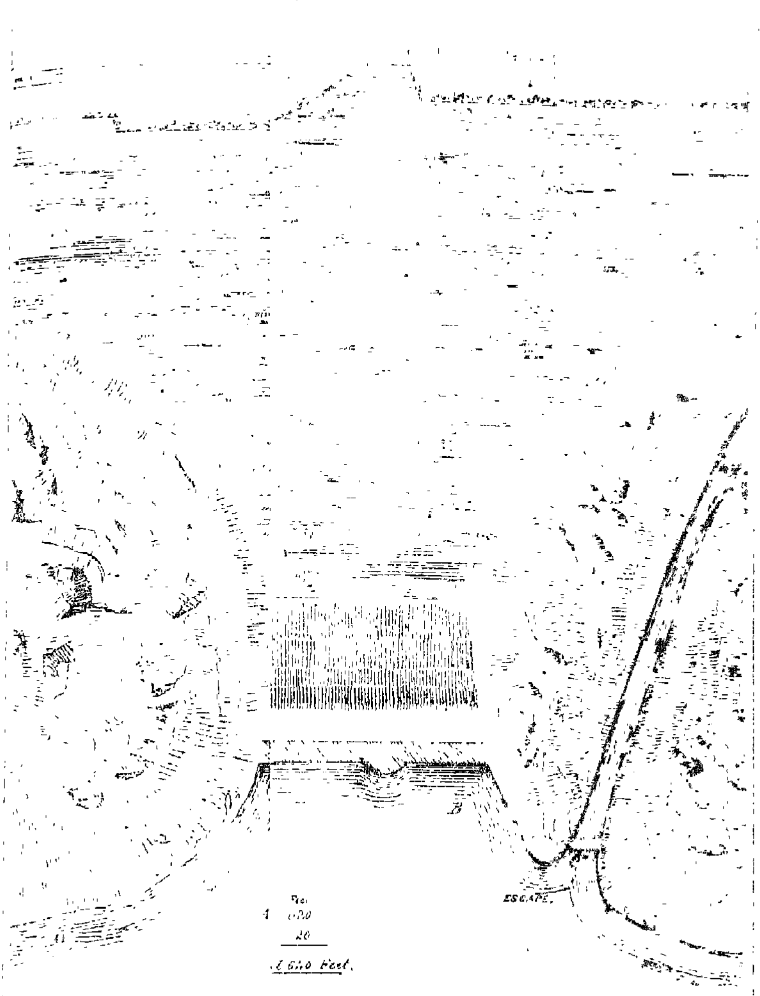
346. The following descriptions of other kinds of Irrigation tanks in Mairwara and Ajmere are from Col. Dixon's work:—

Kabra tank embankment—The Plate gives representations of the plan, section, and elevation of the work. AB shows the bund or embankment blocking up the gorge left open by Nature in the line of hills for the passage of the rain-water. Towards the water-line is the wall of masonry, having three bastions with two flights of steps leading down to the water. The wall of masonry is supported by an earthen embankment, the upper level portion of which represents the terreplein of the bund D denotes the nuddee, or water-course, which has been closed up; whereby the water, collecting in one mass, constitutes the tank. The section through AB shows the thickness of the masonry and earth. The escape, C, has been cut through the hill. It has a wall of masonry towards the water-face perforated with apertures for sluices, through which the water is conducted to drains made of earth by the cultivators, leading to their several fields. The excess of water after the filling of the tank passes over the summit of the masonry wall, and flows off to fill wells and tanks constructed to its rear. A second opening, or outfall, is made in the opposite hill, as is shown in the Survey Map. The elevation gives the appearance of the masonry wall as seen from the bed of the tank when it is dry. The Survey Map affords an intelligible view of the bund, water, and country around. Wells have been sunk in those positions where the cultivated land was too elevated to be irrigated by the sluices. They communicate by small cuts with the bed or sluices, and the water is raised by the Persian wheel, worked by a pair of bullocks. Sections through the kutcha drains made of earth are shown. The references on the plan, give a full explanation of the particulars to which they refer. The dotted lines drawn across the tank exhibit the positions taken up in its survey.

The basin drained by the Kabra nuddee, at the place embanked, embraces an area of about seven square miles. During heavy rains, the stream swells to a mountain torrent. It was therefore a question of the first importance, that the work should be extremely substantial and capable of resisting the pressure of a wide expanse of water, having a depth of 20 feet. The length of the bund is 620 feet; the foundation has been sunk to the rock 9 feet in depth, having a breadth of 27

PLATE LXXII.

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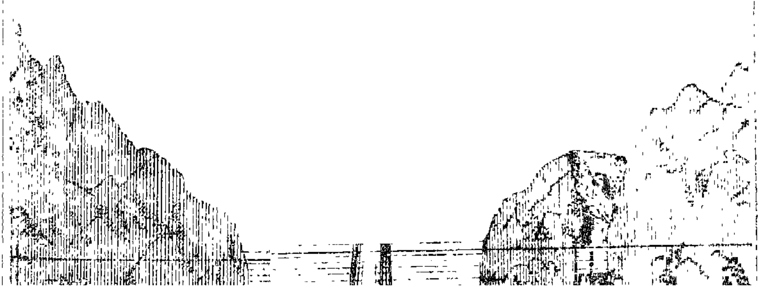
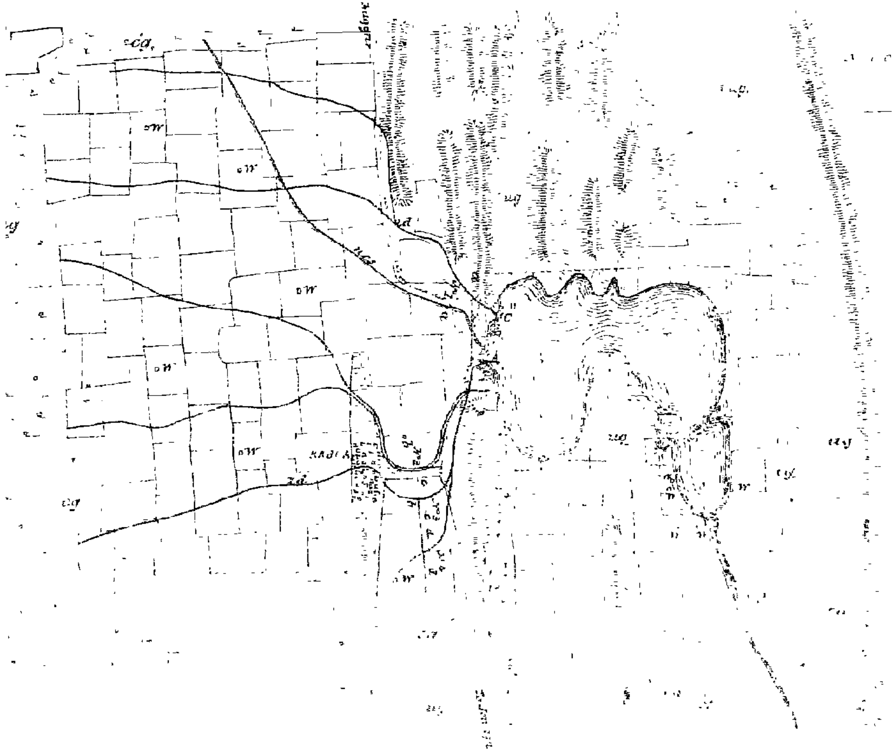
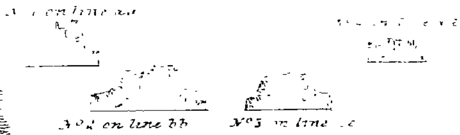


RADHA TALAO



Sections at Chainages



REFERENCE

Length of Tank [illegible]

[illegible]

[illegible]

in the Town

feet, built of stone with limestone mortar. The front wall slightly decreases in breadth as it rises in elevation, each course of masonry having a narrow ledge towards the water-face, as the breadth decreases; the weight of the superstructure is thus kept well within the perpendicular line. By gradual decrease, the masonry is reduced to 10 feet in breadth at the top. Its height from the foundation rock to the summit is 33 feet. The rear embankment, continued through the whole length of the bund, is 70 feet in breadth, its greatest elevation being 25 feet and 6 inches. The water in the tank, after rising within 4 feet of the upper line of masonry flows out by the outfalls on the right and left of the bund. Granular limestone is in such abundance, and so easily quarried, that it has been exclusively used as the building stone. It was contracted for by the Zumeendars at the rate of ten cubic yards per rupee, tools being provided at our own expense. The stone was then carted to the works at a stated contract price. The quarries being near to the bund, this charge was equally reasonable with the original cost for excavation. Earth for the embankment was provided from the bed of the tank, ramps of earth being thrown up for the convenience of the beldars and cattle, as the elevation of the bund increased. Latterly, as the soil immediately in front became exhausted, earth was taken from the rear. The embankment in immediate contact with the front wall of masonry was well beaten down and watered from time to time. The beldars were paid by contract. A low sloping bank was thrown up in front of the masonry, in view to ease off the pressure of the water; and to prevent the earth of the main embankment from being washed away by heavy rain, it has been provided with a dry stone retaining wall from 4 to 6 feet above the surface of the ground. The masonry and the embankment were carried on at the same time; the presence of the earthen bund obviated the necessity for scaffolding, while the earth was well trodden down by coming in constant contact with the feet of the work-people. The work was commenced in 1837, and was completed in two years. Many facilities were offered in its construction. Stone, lime, and wood were in ample abundance and near to the scene of work. Water was the grand difficulty to be overcome during the first season. It was arranged for, by sinking several wells in the rocky bed of the nuddee.

The expense of the work was as follows:—

	RS.	A.	P.
153,121 cubic feet of lime masonry - - -	4,365	6	0
8,830 „ of dry stone masonry - -	121	12	6
725,215 „ of earth well beaten down -	1,758	1	2
Total expense of the Kabra embankment -	6,248	3	8

The expense of the pucka masonry during the first year of construction was at the rate of three rupees and two pie the 100 cubic feet. During the second year, owing to the presence of water in the tank the charge was reduced to two rupees nine annas the 100 cubic feet. Dry stone masonry averaged one rupee ten annas, and earth about four annas for the same measurement.

During the last two years, the sluice in the outlet to the west of the bund has been sunk several feet in depth, in view to irrigate the lands to the rear, and obviate the necessity of Persian wheels, and otherwise economise the labor of the cultivators. Before this arrangement was completed, there were eighty wheels, generally provided with a double line of buckets, continually employed, during the cultivating season, in extracting water for irrigation, which presented a scene of industry scarcely to be surpassed in any country exclusively agricultural. The tank, when filled to the overflowing point, presents the appearance of a beautiful lake, imbedded in the midst of hills, and covering a spread over 450 beegahs, its waters resting on the base of the hills.

Roopana Weir—The Roopana Weir is thrown across a hollow or gorge in a low range of hills, closing the water-course which drains a wide area of country. The foundation rests on solid rock, the breadth of the masonry being 10 feet 6 inches at the base, and gradually decreasing, through an elevation of 18 feet, to 3 feet 3 inches at the summit. The ground to the south-west of the nuddee is secured by a wall of masonry, 6 feet at the base and 4 feet at the summit, having an embankment of earth to its rear, 30 feet in breadth and 11 high. The weir, over which alone the water passes, with the single embankment to the south-west, measures a length of 522 feet. Small bastions have been built in the weir masonry to give stability to the fabric. The water from the weir, after winding its course round the ends of several small range of hills, goes to give productiveness to other villages to the west. The income of water is so great, that the chudur, or cascade, overflows nearly the whole year. Land suited for cultivation is the only desideratum. It is restricted to that confined between the several lines of hills, all of which had to be reclaimed from dense jungle, before the plough could be called into action. This work was constructed in 1846 and 1847, at a cost as below stated :—

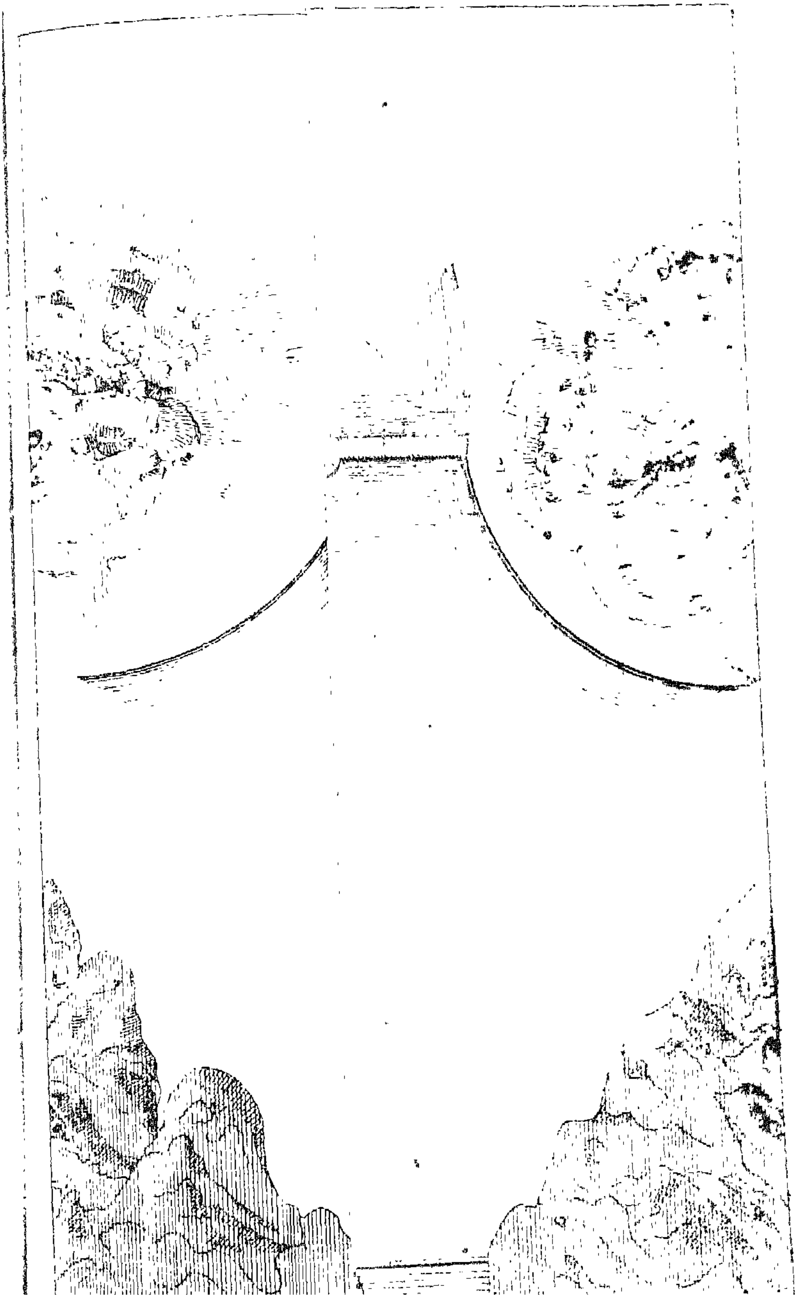
	RS.	A.	P.
43,680 cubic feet of lime masonry - - -	2,095	8	10
73,850 „ of earth - - - - -	110	4	0
Total expense of Roopana Weir - -	2,205	12	10

347. The following extract, from the same author, describes the kind of work referred to above as being applicable to the hill streams of the Punjab :—

Much has been said of the usefulness of small weirs thrown across nuddees, as an auxiliary to irrigation. The plate represents two of such weirs. No. 1, is thrown across the Kabra nuddee, which passes near to Nya Nuggur. It is 315 feet in length forming a straight line, and stretching across the bed of the stream. Advantage has been taken of rocks which crop out of the nuddee ; serving for a firm foundation, and, in some measure, as a rear support to the masonry. The section on *a a* gives a profile of the weir, having a breadth at the base of 10 feet, and of 6 feet 10 inches at the top ; the height rising to 13 feet. The work is strengthened by small bastions to the front. The water maintained in the nuddee by this weir extends to the distance of three quarters of a mile, supplying wells on both sides of the nuddee, and indirectly proving useful by the filtration of the water through the soil.

No. 2 is another specimen. Its length is 145 feet. Half of the masonry rests on a firm rock. For the other half, no hard foundation was attained. The influx of the water after digging 6 feet below the bed of the nuddee was so great, that all

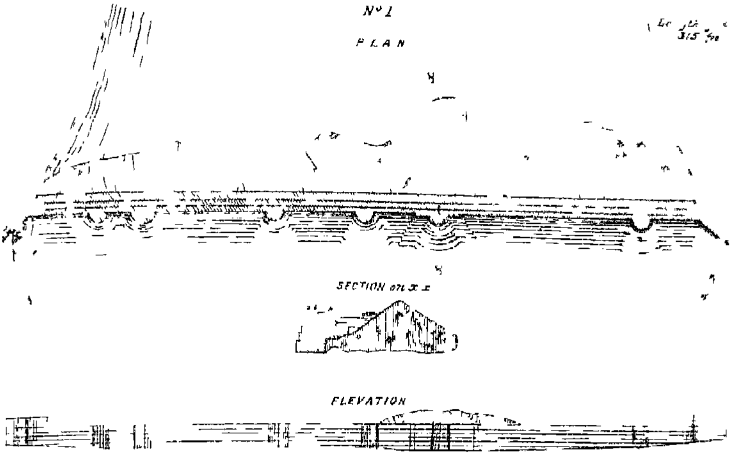
PLATE LXXV



WEIR AT NYANUC[illegible]

at the point where road to Marw[illegible] crosses

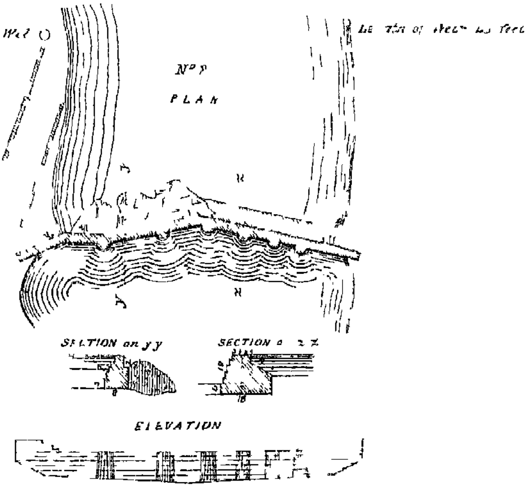
NUDDEE



WEIR AT NYANUC[illegible]

at the point where road to Lynwa[illegible] crosses

NUDDEE



efforts to remove it proved unavailing. The trench was filled up with unslaked lime, and stones promiscuously thrown in, until the water-level was attained, when the masonry was built with stone and mortar in the ordinary way. This work has stood ten years, and is as firm and stable as the day it was raised. The sections on *y y* and *z z*, show the thickness of the masonry. The elevation affords a front view of the weir from its bed, on the nuddee being dry.

In works of this kind, over which the mountain torrents during the rains pass several feet in depth, attention should be directed to the security of the flanks. The masonry at each end of the water-way should be elevated a few feet above high-water mark, and firmly embedded in the banks. With these precautions, the torrent may roar in its passage over the weir without exciting apprehension.

CHAPTER LVII.

RIVER INUNDATIONS—RIVER IMPROVEMENTS.

348. BEFORE dismissing the subject of Irrigation Works, it may be useful to say something on River Inundations and River Improvements, with both of which the Indian Engineer has often to deal.

Inundations.—The tendency of Indian rivers to shift their course and raise their beds by the deposit of silt has already been remarked upon—one effect of this tendency is to cause severe inundations during the rainy season. Nearly all the rivers of the Punjab and Upper India in general, flood their banks for a certain breadth on each side throughout a considerable portion of their course, these inundations gradually increasing as the river approaches the sea where it terminates in an immense delta—which, during the rains is little better than a vast swamp.

Now so long as these partial inundations are confined within reasonable limits, little harm and much good result from them. They do not it is true tend to the healthiness of a district and they prevent any autumn crop being sown on the inundated land—but the silt deposited by the water tends so to fertilize the land that on the subsidence of the Inundation in the cold weather, the richest crops are produced with scarcely any trouble. In such parts of the country it is customary for the cultivators to construct temporary villages which are abandoned when the *rubbee* or spring crop has been reaped—or such villages as are permanently inhabited are built upon natural or artificial mounds, and if necessary defended by a *bund* or embankment.

The autumn crops which lie along the edge of the inundation are also defended by bunds which often extend for miles in length; these bunds are of no great height or solidity, as they are not built where the water is deep and are merely meant to save the crops.

But such inundations, from local causes, often attain to great force and sweeping over the low ground may extend through the heart of a district with a breadth of many miles and a depth of several feet. Houses, villages and crops are swept away—cattle and even human beings destroyed. Moreover the water no longer flowing with a gentle and scarcely perceptible current, acquires great velocity in its course through the low land and having no time to deposit its silt, impoverishes instead of nourishing the soil. An Engineer is often called upon to provide a remedy for such a state of things, and there is no work that demands more patience and skill, and none more anxious or interesting in its results.

Thus it will be seen there may be two classes of embankments designed to provide for two different states of things, viz., (1), long continuous lines of embankment to check the spread of lateral inundations, and confine the river within certain limits; or (2) a comparatively short piece of embankment thrown up to shut out a merely local inundation.

349. 1. The science of Embanking, if it may be so called, is still in its infancy, and very diverse are the opinions of Engineers on the subject. It is contended by the opponents of river embanking in general, that such embankments by restricting the bed of the river within certain bounds, cause such a rapid elevation of the bed from the free deposit of silt, that the waters of the river are year by year raised to a much higher level; the embankments have therefore to be raised and strengthened regularly, so that at last the bed of the river may be raised considerably above the level of the surrounding country, as is the case with the Po in Italy, and the Mississippi at New Orleans—thus, whenever a breach may occur, the inundation is infinitely more destructive than any number of inundations when the river is allowed to take its own course unchecked. On the other hand it is contended, that by confining the river between embankments, the velocity of the current is increased and thus the amount of silt deposited is lessened—that the improvement of the river thus effected for navigable purposes, together with the great area of land annually saved from inundation, more than compensate for the loss caused by an occasional breach of the embankment that the evils of the present system of embanking arise from the want of method by which it has been characterized, and by no means involve the general principle, and that if a certain amount of space be given for the river to expand in on both sides of the cold weather channel, there is nothing to be feared with ordinary precautions. The general question had to be dealt with practically in this country in the case of the Damoodah river, as connected with the alignment of the East Indian Railway. The opinions of different Engineers and of the committee appointed by Lord Dalhousie, to determine the necessary measures, will be found in the Bengal Government Selections.

In America, the question of embanking or non-embanking has been practically settled by the occupiers of the land on both sides of the Mississippi, where, as fast as the ground has been taken up and cleared, bunds or *levees* (as they are there termed), have been thrown up as a defence against the encroachments of the river. The maintenance of these levees is being gradually brought under the control of the States in which they are situated, and Civil Engineers are now generally employed to lay them out, and construct them on the best principles.*

350. 2. Whatever opinion may be formed as to the expediency or otherwise of long continuous lines of embankments, it is still clearly necessary to resort to embanking for defending a country from local inundations, and it is to such therefore in especial that the following remarks will refer.

The first point to be ascertained is the actual locality of inundation at its exit from the river, as this will tolerably define the length of the embankment that will have be to constructed. At the same time the *cause* must be sought for, and this will generally be found to be—a *set* of the river towards that particular spot where the inundation breaks out, with perhaps the existence of a valley or old water-course or ancient bed of the river into which the inundating water flows, and by which it is carried into the interior of the country. It is in general impossible to ascertain the cause of this set, or at least very difficult. For the cause may exist higher up or lower down, or near the place itself, and these rivers, are so capricious in their meanderings, that we know little of the laws affecting their various changes of course.

In some cases, however, the cause may be ascertained and attempts may be made to divert the set of the stream towards the opposite shore. The means to be adopted with this end in view will be discussed further on under the head of "Improvement of Rivers." Such experiments are always doubtful, and usually require to be carried on through a series of seasons to be successful. It is, in fact, battling with a giant and requires great perseverance, energy and skill to obtain any success. Works constructed when the river is low, are often swept away by the first freshet—and the work has to be done all over again. If therefore the damage done by an Inundation be great, but especially if it has a tendency to increase, the difficulty should be at once boldly met and embanking be resorted to as the only efficient remedy.

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* The student may consult Hewson on "Levees," and Ellett "On the Mississippi and Ohio Rivers;" also a very able report which has lately been published by two Officers of the United States Engineers, "On the Physics and Hydraulics of the Mississippi River."

351. The locality of the exit of the Inundation being ascertained, the extreme limits must be found out, that is, the *breadth* of the invading body of water; and its greatest depth should be ascertained at as many fixed places as possible; this will be determined by actual observation during the flood, in a boat or otherwise, and by inspecting the flood marks left on houses, trees, &c., as soon after the waters have receded as possible.

The fall of the ground from the points where the flood depths have been ascertained near the river bank, along the course of the inundation inland, should then be determined by levelling, and this being all plotted down on a plan of the surrounding country, the line of embankment will be determined from the following considerations:—

1st. It is evident that the two ends of the Bund should rest upon high ground not liable to be inundated, or that at any rate the upper end must so rest, or there will be the great danger of the embankment being turned and flooded in the rear.

2nd. If the river, as is generally the case, is cutting away its bank, the bund must be fixed at some distance inland or the river may eat its way to the foot.

3rd. All canals and water-courses (unless it is intended to shut them up) will require Masonry Works over them, where crossed by the Bund, so that a proper quantity of water may still be allowed to pass for the purposes of Irrigation—wherefore it is desirable to cross as few of these as possible, and they should be crossed at right angles.

4th. It is evident that the water when stopped in its onward progress by an embankment, will rise to a much greater height that it did when flowing on unchecked. The greatest height to which it can rise at any point of the bund, will be found by finding the fall from the opposite point on the river bank and then adding to this fall the height of the highest flood mark, observed at the point on the bank. Thus, if the water rises two feet high when overflowing its bank, and the fall from the bank to the opposite point at the bund be four feet—then the water may rise to a height of six feet when checked by the bund. I say, *may* rise, for this will only happen when the water has no free outlet at the lower end of the bund or when the fall down the course of the inundation is greater than the fall down the bank of the river. Nevertheless this horizontal line of still water (as it may be called) should always be taken to determine the height of the bund, three feet being allowed in height over and above this total for safety's sake. As many points therefore on the river bank whose flood marks are clearly determined, will give the required height of the bund at as many opposite points in the proposed line of the bund. It is evident then that the more inland the bund is made the greater will have to be its height, and in all probability the greater its length.

These four conditions will generally determine the line of embankment, which to satisfy them should, (1) have its two ends well secured, (2) not be too near the bank or it may be cut away, (3) should cross as few watercourses as possible and these at right angles, (4) should not be too far inland, or it will have to be made very long and of a great height.

There are also minor points which may have to be considered, such as the taking up of cultivated land, the defending any particular village, avoiding bad soil, &c. The land between the bund and the river will be greatly enriched from the deposit of silt. On the other hand, such portions of any canals as lie between the bund and their mouths on the river bank, will be much silted up, and require heavy clearing after the water has retired.

The height of the bund at various points being determined upon, the line should be cleared and levelled, and then the required height at any number of intermediate points may be ascertained by levelling.

352. The section required for either class of embankment will depend on the depth of water and its velocity. I suppose earth to be the material employed, as stone would be rarely procurable, and generally much too expensive.

Unfortunately we have few rules to determine the necessary thickness of material to resist water in motion. We can calculate the mere dead pressure from the depth and area of the surface pressed, but the two great practical dangers to be guarded against, come under no fixed rule. These are, 1st, The tendency of the water to cut against the slope of the bund, either from the velocity of the stream or when agitated by waves; 2nd., The soaking of the water through the mass of new earth, which, unless speedily checked, will cause breaches in many places. It is evident that both of these dangers diminish in proportion as the bund gets older and the earthwork has time to consolidate—it is during the first year that the greatest danger occurs. There is also a third source of danger which should not pass unnoticed, and that is the holes made in the embankment by rats or other vermin.

The thickness of the bund at top will depend on whether it is also to be made use of as a public road or not. The traffic on it tends to consolidate the earth, but it is also apt to break it down, and lower the crest. In the Plate an arrangement is shown for joining a road on to a bund, which obviates this objection. A top width of 6 to 10 feet will generally be sufficient, with a rear slope of 1 or 1½ to 1, according to the nature of the soil. On the water side, the slope cannot be too long for safety, and the degree of its flatness is a mere question of expense. It ought never to be less than 3 to 1, and, in general, should not be less than 5 to 1.

The earth should be thrown up in layers and well rammed, and the surface soil loosened to make the new earth bind better with the old. Sand may be allowed for the heart of the bund, but not for the two slopes. Stiff clay is apt to crack and is not so good as light clay or good alluvial soil. Shrinkage should be allowed for, as in the case of Road Embankments. The amount depends on the nature of the soil, and usually varies from ⅕th to $\frac{1}{10}$th the original bulk.

The earth for the construction of a bund should on no account be taken immediately from its front, the effect of which would be either to deepen the pressure of the water against it, or to make a dangerous stream along its face. No excavations should be allowed within 20 feet of the toe of either front or rear slope.

353. When the foundation soil is very boggy, it may be necessary to seek for an artificial foundation to support the bund. American writers recommend brushwood, as in the case of a road bank, but the danger of leakage is very great, and may result in the new bank being undermined and swept away. If draining is too expensive, the sub-soil may be consolidated by wooden piles made of any common wood, and driven in 4 or 5 feet deep, or the earth may be excavated for 3 or 4 feet, and the excavation filled in with sand. A simpler and cheaper remedy is to use *sand-piles, i. e.,* a wooden pile of about one foot diameter is driven in some feet, and then withdrawn, the hole so made being filled in with rammed sand,

and this is repeated at intervals of 3 feet or so in each direction over the whole of the boggy surface.

If possible the water-slope should be artificially protected. The best plan is to turf it, or at least the lower half of it; but unless grass and water are plentiful and close at hand, the expense would be too great. Grass roots may be dibbled in here and there, or grass seed sown and well watered. If none of these can be managed, then loose brushwood may perhaps be available, or coarse mats and *chuppahs.* In Holland straw is used for the some purpose, twisted into ropes about 2 inches in diameter; it is laid on the face of the bank and pinned down with forked sticks, rope after rope being added till the whole slope is covered.

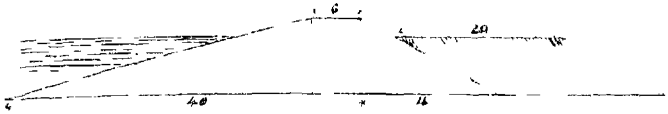
Any dry streams or water-courses crossed by the bund should be carefully filled up for a certain distance in front, as when the inundation first breaks out these nullahs are filled with water, which will often run down their course and cut clean through the bund, even before the water has attained any height. Wherever such nullahs appear either at right angles to, or oblique with, the bund, it is advisable to throw out *spurs* of brushwood and piles nearly perpendicular to the stream of water to divert the set of these streams from the bund. These spurs may be made of a double row of piles of jungle wood, about 4 feet apart and filled in with brushwood —they should be higher than the water, and may be necessary in considerable numbers, as in the defence of a river bank.

In crossing canals, Regulators will be required, made after the ordinary manner of regulating bridges, the roadways being level with, and connecting, the top of the bund.

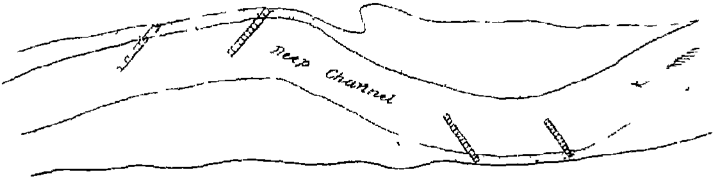
In a new embankment, the greatest watchfulness is necessary when the water comes up, to prevent breaches. Gangs of workmen should be stationed all along, well supplied with mats, piles, mallets, &c. As soon as the water is observed to be soaking through at any place, mats or brushwood should be put in front to stop it, and if a regular leak occurs underneath, the bund must be well cut into and the leak discovered and stopped. If the slope is being cut away, piles and brushwood must be applied to remedy it, and a spur thrown out to divert the set of the water. If a break occurs and the water rushes through with any force, as is generally the case, it will be almost impossible to stop it—the only thing to be done is to defend the sides of the breach with piles and brushwood to prevent it increasing, and to wait the first falling of the water to repair it. Breaches,

PLATE LXVII

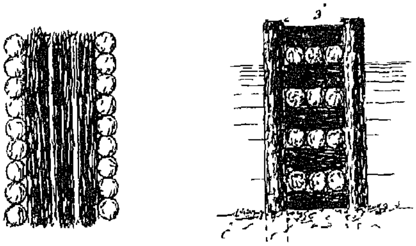
Section of flood Embankment with Road attached



Mode of defending a River bank by spurs.



Plan and Section of Spurs.—



however, may be occasionally stopped with tripods made of piles placed in a row,—and stout chuppahs in front. Sacks of earth in sufficient numbers thrown into the breach are also useful, or old boats may be sunk.

Sluices of masonry are often fitted to bunds to irrigate the lands to the rear. It is better, however, not to fix them until the earthwork has proved itself firm.

354. *Improvement of Rivers.*—In forming plans for the Improvement of Rivers, the following are the objects generally to be kept in view; 1st, The means to be taken to protect the banks from the action of the current; 2nd, The means to prevent inundations of the surrounding country; 3rd, The removal of bars, elbows, and other natural obstructions to navigation; 4th, The means to be resorted to for obtaining a suitable depth of water for boats, of a proper tonnage, for the trade of the river.

1. To protect the banks either artificial means must be resorted to, to divert the action of the current along the shore, or the banks themselves must be artificially protected. The latter plan can only be used when the banks are high, and not liable to inundation and the soil of not too loose a texture. If they are perpendicular, they should be cut down to a gentle slope and defended by a revetment of turf, stone, &c., by sowing grass seed, or by planting low jungle or aquatic plants.

In Flanders and Holland, when a bank is to be protected, if the erosion take place *above* the ordinary water line, and the natural slope of the ground below such as to support the weight of the bank, fascines are laid in horizontal courses and bound together by stakes running into the bank. When the bank is eroded *below* the ordinary water line, the course adopted is to form a species of raft of gabions strongly tied together and fixed into the banks by stakes, with their ends projecting into the stream. Other gabions are placed on these in a direction parallel to the bank, and fascines alternately crossing one another in the body of the raft, are laid upon this grating. The whole structure is firmly bound together and sunk by being loaded with stones or bags of earth. Large hollows in the bank are filled with panniers loaded with gravel.

It is evident that the expense of the above methods must preclude their adoption for any great length of shore in general. The set of the water against a bank can however often be altered by constructing fixed or floating spurs running out from the shore which deflect the current to the opposite side.

These spurs may consist of two or three rows of piles, the interval, being filled with brushwood, which stand well against the stream, and by checking it and causing a deposit of silt, gradually effect their purpose. It is calculated that such a spur will defend seven times its own perpendicular length from the shore, viz., four times its length below and three times above. For economy of construction, therefore, the more perpendicularly such spurs are run out from the bank the better, but as the force of the water is often so great, that if placed perpendicularly to the thread of the stream, they would never be able to stand, and as the effects of the back-water at the root of the spur are also very great, I have found that an inclination of about 45° should, in general, be given to them. A system of spurs should be so arranged, that the next one is put where the first one ceases to act, and the tops should in all cases be well above the surface of the water, so that the surface velocity may be checked as well as the under current. If the object is merely to protect the shore it is better to use a greater number of short spurs than smaller number of long ones where the breadth of the current is considerable: it is evidently useless to to run the spur into the slack water beyond the current. If the object, however, is to deflect the current to a considerable distance from the shore, so as to alter the *set* of the river, then long spurs must be used.

355. The following is a description of the brushwood spurs constructed between 1855-58, to defend the Cuttack Revetment Wall from the action of the Mahanuddee river :—

In 1856 a brushwood spur was constructed, the result of which was a two-fold one. Further silting up of the hollows under the revetment wall took place, and the line of deep channel of the river was diverted from a course dead on the revetment wall to a very favorable one, parallel to it. The spur consisted of a double row of piles driven 3 feet apart from centre to centre, and a width of 3 feet between the rows. These piles averaged 15 feet long and 8 inches in diameter at the head. They were driven 7 feet into the sandy bed, and according as a length of two or three hundred feet was completed, the space between the rows was filled up for a height of 6 feet, with fascines of brushwood, firmly packed and trodden down. The top was then tightly bound down by coir ropes, crossed from pile to pile, and the whole was thus rendered very firm and secure. There was no attempt made to weigh down the fascines with stones, as it would have been too expensive, and the result proves that this was not required, for, when the water rose over the spur, none of the brushwood bundles showed any inclination to rise, float away, or resist being confined within the original space allotted to them.

In 1858 a second brushwood spur, was constructed by Mr. Armstrong, C.E. It was 1,923 feet long, and constructed similar to the one in 1856. This spur cost 5 annas per foot run ; the one of 1856 cost 8 annas per foot ; the difference is owing in part to the fact that the last built spur was erected during the dry weather, while that of 1856 was constructed in water. The great saving however was effected in the pile driving. The engine formerly used could only drive 24 piles per diem, with 16 men; the light ringing engine used for the second spur required only 12 men, and drove on an average 50 piles. To assist the action of this spur, brushwood dams were run across the deep pools in the river, at various distances, from 100 to 200 feet apart, according to the depth of the water or the state of the revetment's foundation. These dams were formed of three or four fascines, in the centre were placed one or two stones, according to their size, and the fascines tied firmly round them with three coir ropes, one at each end and one in the middle; these bundles were about 5 feet long and 2 feet in diameter in the centre, and at the end 12 inches or so. These works were quite successful in their object.

356. Where stone is available at a cheap rate it is generally the best material for these works, especially when the depth of piling is great, as timber piles of any length are often very dear. The following practical hints on such works will be found useful.

For works in depths of over 2½ fathoms, use the largest stone available; small stone, used merely to fill up the interstices between large ones, being useless—wasted in fact. The base of the spur may be laid out a few feet more than double the height; the stones will stand well at slopes of 1 to 1, and there is no necessity for more than a few feet in width at top. In depths of from one up to two and a half fathoms, use ordinary guide and sheet-piling, like the sides of a common cofferdam, with a line of brush-wood about 6 feet wide and 2 feet deep sunk on either side, to prevent washing about the feet of the piles. In depths of less than one fathom, two rows of jungle-wood piles, driven at distances of about 3 feet apart each way, the space between being filled in with brush-wood secured down with clay, or stones, &c.

As the depth of water in which the large spurs must be built is often considerable, it will be necessary to adopt every available means which may be likely to economize material; the following plan has often been found to effect a great saving. The spur should at first be laid out only large enough to allow of its being carried up to the level of low water; as it will generally be found that, when the stone-work is carried up to this level, a shoal will be formed on one side, or perhaps, on both sides of it. When the shoal is completely formed to the level of the spur, a line can be set out on the shoal and old spur, of dimensions sufficient to allow of its being carried up to half-tide level. Half-tide level will generally be found high enough to carry the stone-work; but if, when the shoal forms up to this level, more be found necessary, another can be laid to be carried up to ordinary high-water. By proceeding in this way, a very great saving may be effected if the scheme be successful; while, if it fail, that is, if silt do not accumulate as the work proceeds, the worst that can happen is, that the spur must be carried up as it would have been if the attempt had not been made.

When building in currents, the site of the spur should be covered *completely over* with about a foot deep of small stones, or very coarse gravel, before any part of the work be carried up more than a few feet in height. This precaution is necessary whatever kind of spur be used: if it is not attended to, the current, which always runs round the spur-head, will deepen the site of it as the work proceeds, so that a work which was intended to have been in 10 feet of water may be really carried out in 20. The deepening goes on gradually and almost imperceptibly: but the loss of material caused by it is often very great. In the case of small pile and brush-wood spurs the piles may be all driven first, and then a thin layer of brush-wood put over the bottom, before any part of the body be raised.

357. Floating breakwaters, consisting of an arrangement of logs made more buoyant if necessary, with casks, are also recommended for deepening the channel of a river, protecting a shore from inundation, or removing a sand bank. If these floating logs are moored on the edges of the navigable channel, athwart the stream, the current would be thrown more into the bed or middle of the river (from the corner where the logs are supposed to be fixed), till it is opposed by the next log fixed at the next corner; whence, again, a new and improved direction of the current may be given; by thus working at the different corners where the stream has a set on the shore, and is tending to increase the elbow already formed—and remembering always, that the angle of incidence is equal the angle of reflection, which will determine the inclination of the logs, a considerable effect may be gradually produced by the bulk of the water being impelled into the middle of the channel.

If the connected logs, are, instead of being placed athwart the stream, so situated as to keep back the water contained in its channel, and are kept at command by having chains at one end secured to the bank, and at the other end so fixed as to maintain the logs directly across the current, and if this be done on both sides of the river, there will be a rush of water between the ends most distant from the banks, which will constantly act in deepening the passage in the middle, and generally along the bottom. Wherever shallows occur, this method would be applicable.

In this way floating spurs can be fixed, being moveable as on a pivot at their shore ends. These logs should always be moveable, so that their inclinations may be altered as the set of the stream gradually changes, and that they can be removed during flood time. Their depths and breadths must be proportioned to the power of the river.

358. 2. To *prevent* Inundations, either the *set* of the river must be altered, or Embanking must be resorted to, or a freeer outlet must be afforded to the flooding waters in their course down stream. To effect the *first* the means already described may be resorted to, the attempts being continued with perseverance through several successive seasons. The *second* has been already treated of.

The *third* remedy is often applied by straightening the bends of a river, so as to increase the fall, and, therefore, the velocity of the stream, but the system is now generally condemned, unless it can be carried out down the whole course of a river. For the effect of straightening any particular bend by a *cut-off*, is simply to save the land above at the expense of that below, the flood waters being thrown into the river below the cut-off more quickly than they can be passed on, while nature revenges itself in the end by caving out the banks until the velocity of the stream and resistance of the banks are again equalized, or perhaps, by establishing another bend. The greatest benefit to be given in this direction would be by confining the exit of the water to one channel through the delta, whereby the depth of water would be increased, bars at the mouth swept away, and the flood waters above passed off. Of course, such an operation on the delta would involve great expense and much Engineering skill, but both money and skill would be expended in the right direction.*

359. 3. The most common obstacles to Navigation in Indian Rivers are rocks—kunkur banks—sunken trees—and sand or mud banks. The last are best removed by diverting the current of the river against them by means of spurs as above described. Dredging may also be resorted to in particular cases, but it is generally very expensive and attacks the effect and not the cause of the shoal. The works generally employed for the removal of these shoals in Indian Rivers are called *bandels.*

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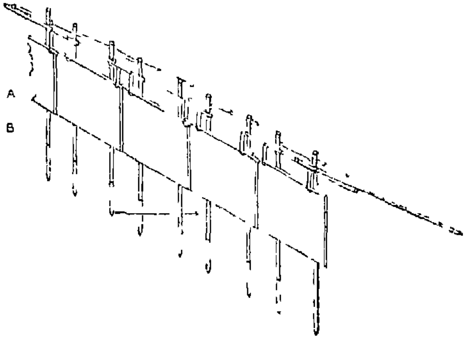
* The Amazon, which discharges its waters by a single mouth, carries them 150 miles into the sea, and effectually prevents the formation of any bar. The mouths of a delta river carry on the silt a short distance at a feeble rate, when it is met by the tide, and thrown up in the shape of bars.

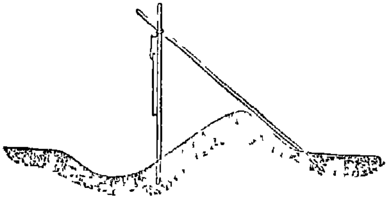
They consist of bamboos fixed at intervals in lines inclined to the stream—along these others are tied longitudinally, on which mats are hung facing the stream, the rear being supported by struts. In constructing these, two points have to be attended to. The piles after being well shaken into the sand should be driven down with mallets, and in placing the mats a space shown at AB must be left between their lower edge and the bed of the stream—the mats over-lapping one another.

Fig. 1.



The action of such a work is to collect the sand carried by the stream and deposit it at the back of the bandel. If the mats were carried to the bottom this would not be the case, and hence a space is left for the water to pass carrying the sand with it, and which as a rule, cuts a deep trench in front of the bandle, as shown in Fig. 2.

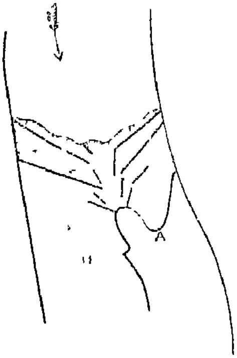
Fig. 2.



The defects of this system are—1st, Its buoyancy; 2nd, Its porousness; and 3rd, Its limited application, due principally to the first defect. If the materials were heavier, then it might be placed in deep water; but to retain it for any length of time, even in the shallowest parts of the stream, it is necessary to have the piles constantly driven down, as they are always liable to be washed up and floated away.

The second defect, arising from the openness of the mats, is not so detrimental as the former. A certain quantity of water passes through them without being of the slightest use. On the contrary, its effect is rather injurious; for it increases the current at the back of the bandel, and assists in carrying off the finer particles of sand, which would go towards the accumulations in the rear. In some cases it is requisite to stop the current altogether, under these circumstances the mats but very imperfectly perform their intended office.

Fig. 3.



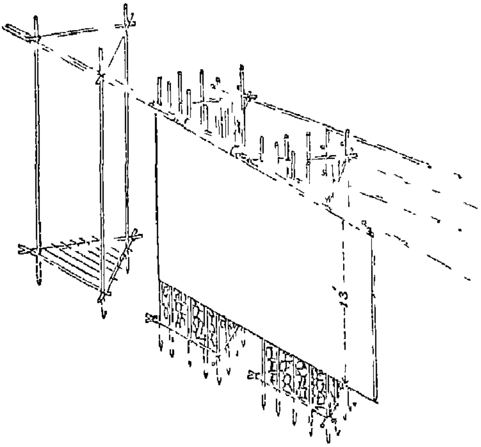
Bandels are generally arranged as shown in Fig. 3, which represents their position when first laid down. After they have been in operation some little time, the sand will commence to accumulate at the lower end and will fill up as far as A. To meet this lengthening of the channel, other lines of bandels have to be added, and continued as far as the filling up extends.

360. The following improvement on the common native bandel has been tried with success by Mr. Longmore, on the Ganges and Bhagiruttee rivers. The construction is fully shown in Fig. 4.

These *groins* were formed by a number of piers, triangular in shape, placed at intervals and tied firmly together.

Each pier was constructed thus—3 piles were driven to form as near as possible an equilateral triangle; over these a triangular curb, crossed with

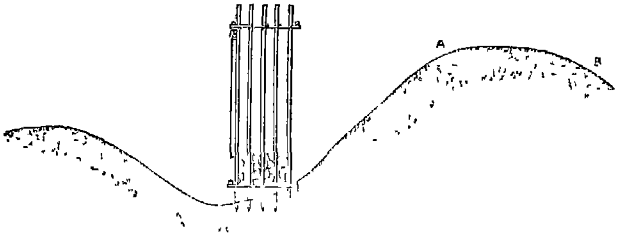
Fig. 4.



small bamboos, to form a sort of gridiron, was dropped and forced to the bottom.

The upper part was then tied to form a triangle similar to the lower, and piles were driven at intervals along all these sides and the interior filled with sand bags, made of mats rolled into a cylindrical shape and well rammed. After this the mats were applied, measuring 20 feet × 3 inches, made by tying the small mats on to a framework of bamboos. As soon as one side of the frame was fastened to the piers, the boats carrying them were withdrawn, and the force of the current carried it close in; often with such force as to make the whole groin creak and bend again. To prevent the escape of any of the sand bags, the lower curb was fastened to the top one with stout string.

Fig. 5.



The triangular shape of the piers was found advantageous. The water rushing through the opening between the piers spreads out on either side, cuts away the sand and tends to tilt the pier over—this is counteracted by the struts, and its connection with the other portions of the work—the sand under and in front is then cut away, and the pier sinks; in some cases inclined forwards, in others to the rear, but generally vertically, depositing a great mass of sand behind (*see* Fig. 5). In a depth of 12 feet, 10 feet have been shoaled up in the course of a couple of days, extending in one line for a distance of 150 yards, and at least 15 feet broad.

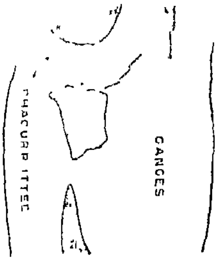
All the coarser sand is deposited at A—the finer is carried and deposited in the direction of B.

361. It is impossible to lay down any rule or number of rules, that shall be applicable to all the various phenomena of the river,—for fixing the sites of such works. Each reach of the river requires different treat-ment at different periods of the same season, and in each year invariably so. In laying down any principle for guidance, the chances are that the physical characteristics on which it is based, may not be fully recognised, and it will therefore be a failure.

The contour of the banks may be safely taken for guidance when the river is high. The deepest and strongest current will run along its concave side, from whence the bed will gradually slope up, forming a sand bank or shoal on its convex side. And a shoal generally exists running obliquely across the river, from the point where the current passes, and from one bank to the other. But when the river is low, the banks afford very little indication where the current is deepest and strongest.

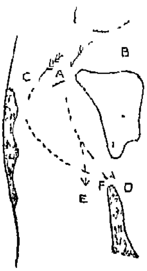
Before deciding upon any line of action, it is very necessary to take soundings regularly, to ascertain any change that may be taking place in the bed of the stream, and to what part it is likely to tend. In case it has to be diverted from one direction to another, it is best to work in curves as much as possible, that the water may lose but little of its initial velocity; but where the channel can be made straight and preserved so, it should be carried out accordingly. For diverting the main stream of the Ganges, curved groins, arranged as in the figure, have been found to answer exceedingly well.

Fig. 6.



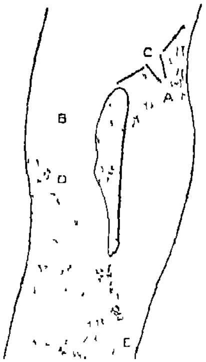
It is often difficult to determine the effect a proposed groin may have when there are a number of channels and currents. This will be shown on reference to Fig. 7. A strong current runs down B to A, passes and divides into two currents D, E. A groin at A, it might be supposed would divert more down to E: it may however have a contrary effect, for the current at A finding itself arrested would turn off in the direction C and form a curve to F, a direction less favorable for the current down E. Then it might be urged that closing D would answer this end. Even this is problematical. For the draw on the current down B, which must be kept deep, would be slackened, and it would tend to silt up, except it was closed long before the river reached its lowest.

Fig. 7.



In deepening a shoal the two nearest and deepest portions of the upper and lower reaches should be connected, even though somewhat oblique to the current, when the quantity of sand to be carried off is less than where the current is more direct. For, apart from the greater quantity of sand to be removed and the tendency of the stream to economise its own force, it will be found, that the relative levels in the two reaches are different (*see* Fig. 8). A will be lower than B, and for this reason, that in A, there is nothing to back up the stream higher than E; whereas in B, it is backed up from D, causing a head of water there which is all employed in forcing itself and its sand down to E. The difference of level is only apparent when the stream has nearly reached its lowest point. Bandels arranged at C, before it has reached this, would aid in opening a channel, and be ready for the lowest state of the river when a current would set through it, and to assist which the bank at D should be shoaled up.

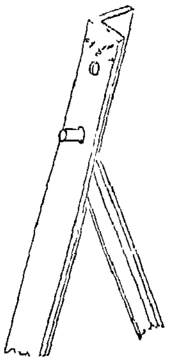
Fig. 8.



362. The chief defect in the native bandel—its buoyancy—has already been noticed. To remedy this, it has been proposed to use wrought-iron sheets instead of mats, retaining the bamboo piles and struts. The weight of the sheets would keep these in their position and prevent their being washed away. In addition to which, being impervious to water, their action would be more complete, and further would afford the means of cutting off a shallow current entirely, which is often very desirable, but with the old bandel quite impossible.

For deep water, a larger bandel has been suggested, made principally of iron, *see* Fig. 9, which shows the junction of the strut and pile, both made of angle iron; the facing might be of mats as usual. It would probably act very well and be quite sufficient for all the more important works and the common bandel, when improved, as suggested, would be found amply sufficient for minor works.

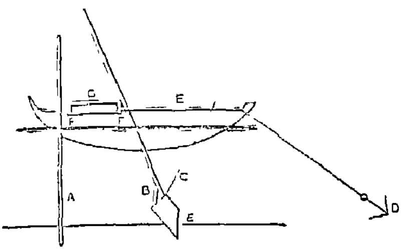
Fig. 9.



The expense would not be greater than the present system; as one line would be as effective as three ordinary ones, and though the first cost would be a little more, still in mats and bamboos there would be a great saving, without taking into consideration the immense amount of labor that would be saved, both in construction and in keeping down, *or in attempting* to keep down, the old style of bandel; and which, in spite of all precautions, causes great loss by being washed away.

363. The following simple dredge has been proposed by Mr. Longmore, for opening a channel through shoals when bandels had already been constructed. A simple apparatus, to be worked by hand, is all that is necessary; 5 or 6 feet is all it would have to work in, and that principally at the upper end of the channel, when the current being slacker there would be the most need for it.

Fig. 10.



A—Pile for keeping boat steady.

B—Scoop.

C—Rope for raising scoop.

D—Anchor.

E—Platform on which to throw the stuff.

FF—Beams tying sides of boat.

G—Platform for men to work the scoops.

Raking up the sand, by drawing a "burrow" through it to be carried off by the stream, has been tried, but found not to answer. This would be very effective in clay, or clay and sand, but in sand alone, lying for some distance along a shallow channel, its action would be very limited.

364. Sunken trees are generally removed by blasting, and the following account of work of this kind as actually carried out on the Gogra river, in Oudh, by Lieut. Carroll, R E., will give all needful details, and be found useful by those undertaking similar work:—

It is necessary, in the first place, to describe the general features which produce the difficulty of removing a sunken tree. The current of the Gogra flows in many places $2\frac{1}{2}$ miles an hour, or 3·6 feet a second. This speed is quite common round the edges of a kunkur rock, or between the branches of a sunken tree; in many such places it is much higher than this, and as the pressure of the current is proportional to the square of the velocity, the difficulty of working boats, or placing charges of gunpowder may be considered to increase in the same ratio. The trees are found sometimes wholly, sometimes partially, immersed in the channel, or they are found partly or wholly buried in the sands, and only creating danger in the rains, when the floods rise over their branches and hide them; or they are found thrown up on the sands and not imbedded, or lying fallen on the banks ready to be swept in at the next floods; but wherever they are found, they offer a very indifferent mark for the action of gunpowder. The roundness of the branches and their small surface compared with their strength, the toughness of the roots, and the massiveness of the stem, combine to make the removal of a large tree a tedious and difficult matter. It presents no large and weak surface like the hull of a sunken ship, and it lies usually in shallower water which offers less resistance as tamping to the charge. When broken up, the pieces, often of great weight, have to be dragged in and lifted up upon the high main bank, to prevent their being again carried into the river during floods, and becoming fresh obstacles. The above description applies to the largest class of trees, of which many have been found with stems 10 feet and more in diameter. The removal of a small tree is of course proportionally easier.

The means employed for the blasting of trees last year, in the absence of better ones, were charges of from 25 to 50 lbs. of gunpowder, contained in tin cylinders, and fired by means of tin tubes rammed with fuze composition, and attached to the cylinders by a water-proof joint. The cylinders were provided with loops of ron-wire projecting from the side, by means of which they could be lowered into the selected spot, by sliding them down bamboos, previously driven in and stayed against the branches of the tree. This method of placing the charge has been retained, as it is found that no moderate weight attached to the cylinders will retain them in their places in a strong current, and because in many places a diver cannot be safely sent down to place the charges.

365. The mode of firing by fuze tubes was abandoned as soon as possible; it was very inconvenient at any time, and the tubes were liable to break; they were also very uncertain in depths even of 6 feet, and they could not be employed at all in considerable depths.

Another method of firing charges employed last year, and in the present, has been found very effective and,—granted that the cylinder and tube have been properly tested,—it is perhaps the most certain of all. Instead of the thin tin tubes above described, a tube of about three-fourth inch diameter is employed, and soldered into the cylinder near one edge. A thin bamboo lashed to the cylinder and tube secures the latter from being injured, and the cylinder and tube thus prepared and tested can be stored in the magazines ready for use. The testing is done simply by filling the cylinder with water, through the tube, till the latter is full to the top. If the cylinder will stand the pressure of a 10 feet head of water thus applied without leakage, it will bear to be immersed (when filled with the charge) to a depth of 15 feet, or if very tightly filled, to a depth of 20 feet. The charges thus prepared may be placed, as before described, by sliding them down on bamboos into the chosen spot. The firing is effected in the following way, which I believe to be novel. Into the top of the tube, which projects above water, is fixed a fuze which is rammed in a tin tube 9 inches long and of a slightly conical shape. The composition of the fuze contains near its head a pellet of iron of about half the diameter of the lower end of the tube. The burning of the fuze makes the pellet red-hot; it is prevented from blowing out upwards by two cross wires, and consequently when the fuze has burnt out, the pellet drops through the tube, and ignites the gunpowder. A large number of charges have been fired in this way, and no failure has ever occurred through the pellet's not falling or not being hot enough. Charges thus prepared have been used in from 15 to 20 feet of water, and it is manifest that with flexible tubing, such as block tin gas-pipe, that they might be employed in much greater depths and with some advantage where time did not admit of the construction of a galvanic battery. The fuzes should be rammed with ordinary fuze composition, which is a mixture of—

	lb.	oz.
Saltpetre, ...	3	4
Sulphur, ...	1	0
Mealed powder, ...	2	12

and care should be taken that the pellet is always considerably smaller than the tube it has to fall through, and that it is not angular in shape.

366. The Magnetic Battery has also been employed this year with success, and though the mode of using it and the construction of the fuzes are amply detailed in Messrs. Wheatstone and Abel's Report on the subject in Volume X. of the Professional Papers, Royal Engineers, part may be repeated here in order to render the account of the rough but effective fuze here employed more distinct.

The ordinary fuze consists of a wooden plug carrying a gutta-percha core nserted through its axis, and containing two fine copper wires insulated from each other. The core projects three-fourths of an inch from the lower extremity of the plug, and its end is cut off clearly, so as to expose the extremities of the wire, which are one-sixteenth of an inch apart. The upper ends of these insulated wires are separated from each other, and put into connection with two small copper tubes or eyes, which are fixed crossways in the head of the plug. These eyes are intended for the reception of the main wires of the battery, and the current in passing has to flow by the insulated wires contained in the core of the fuze, and to leap the interval of one-sixteenth of an inch which separates them. To enable it to do this, the exposed ends of the wires are covered with an explosive composition of feeble conducting power, consisting of an intimate mixture of the following ingredients:—

Sub-phosphide of copper, . . .	10	parts
Sub-sulphide „ . . .	45	„
Chlorate of potassa, . . .	15	„

About a grain of this composition is inserted into a small cap of metal foil which is twisted on the end of the gutta-percha's core; and the bursting charge is contained in a tin tube of a few inches in length, which is fitted on to the end of the fuze plug, and corked at its lower extremity.

When the fuze is about to be used, and has been prepared in the manner described, the end of the wire which leads from the battery is pressed into one of the copper eyes, and another shorter wire is pressed into the other eye, and its upper extremity put into connection with the outer surface of the vessel containing the charge, if it be of metal or with a metal plate attached to it; if it be of wood, the circuit through the fuze and main wire is completed by the water between the surface of the cylinder (or the metal plate), and a metal plate attached by a short wire to one of the poles of the battery, and immersed in the water. The neck of the cylinder through which the fuze has been inserted is of course stopped with a water-tight plug. The charge being thus prepared and placed, the boat containing the magnetic battery is withdrawn to a convenient distance, and the charge is fired by a smart turn of the handle of the battery, which, by causing the armatures of the magnets to rotate before their poles, produces the succession of induction current necessary for ignition. The main wire leading from the battery must be carefully insulated from the water, and the connection of the return wires with the water carefully made. The other connections with fuze and battery need not be made with as much care as when working with the galvanic battery, for, here we have to deal with electricity of higher tension than is produced by any galvanic battery of moderate power.

367. This description of the fuze and its use, all of which may be found in greater detail in Messrs. Wheatstone and Abel's Report, above referred to, will enable me to dispose of the rough, but effective fuze, here employed in a few words. In place of the wooden plug, a cork is employed, which does the double duty of holding the gutta-percha core and of corking the cylinder. The core itself, instead of the carefully manufactured article above described, may be simply made by taking two pieces, each a few inches long, of single insulated copper wire cut from the coil employed as main wire, cleaning them for about half their length, and fuzing them together by passing a hot iron over the gutta-percha with which they are covered. They are then pressed together till the ends of the wires are one-sixteenth of an inch apart. A shorter interval may be employed with advantage, say one-twenty-fifth of an inch. This core is passed through the cork, and the portion of the fuze wires which have been cleaned and exposed, project above it for the purpose of making connections. One of these, supposing the fuze to be primed and placed in the cylinder, is bent over and put into connection with the metal of the cylinder generally by folding it up with a little slip of tin projecting from the neck; the other is put in connection with the main wire of the battery.

The priming of the fuze is previously effected by cleaning the inner end of the core, wrapping a small paper cartridge round it, inserting a grain of the magnet fuze composition and filling the rest of the cartridge with mealed powder slightly rammed, to prevent it and the fuze composition from separating from the end of the wires. The end of the cartridge may be plugged with wax. This small cartridge is quite sufficient as a bursting charge for 50 lb. charges; but for larger charges, a larger one would be preferable, and could be tied round the cork, which would then be passed altogether into the charge, and other arrangements made for corking the cylinder.

A water-proof substance must always be employed to cover the top of the cork, and protect the connection of the main wire with the fuze which is just outside it, from the water. The substance here employed is that called Kitt composition; it consists of a mixture of the following ingredients, slowly heated together:—

	lbs.	oz.
Resin,	7	8
Pitch,	6	14
Bees' wax,	6	14
Tallow,	1	14

In warm weather it should be kept cool in water, or it becomes too soft to use with convenience; in other respects it is perhaps the best and most flexible water-proofing that can be employed—an important point where any fuze or wire leading from the cylinder is liable to flexure or vibration.

The only precautions that are necessary to be taken with these fuzes, beyond the perfect insulation of the main wire from the water, are that its connection, which is just outside the cork, should be kept out of contact with the surface of the cylinder, and that the cylinder itself should not be washed over with any water-proofing which would insulate it from the water and check the return current. The main wire should also be tied to the cylinder, so as to prevent any strain coming on the fuze or its connections.

The percentage of failures with these fuzes has been exceeding small. Out of 60 charges lately fired in depths of from 8 to 20 feet of water, and varying in amount from 50 to 450 lbs., there have been only two failures; and these were due probably to defective insulation of the main wire and not to the fuze.

368. The Magnetic Battery and insulated wire were obtained from the Telegraph Department; the latter is copper of about one-eighteenth inch diameter, coated with gutta-percha. The battery is contained in a box about 14 inches square and 9 inches high. Its great advantages over the Galvanic battery are, that it requires the use of no liquids; it is always ready for use; its power is constant; and it is more compact and less liable to injury. The magnet fuze composition was prepared at Calcutta, but as it may sometimes be impossible to procure it, it is important to know a substitute. Mealed powder* when moistened to a certain extent is an excellent one. The mode of preparing it is described in the Royal Engineers' Professional Papers before referred to, but may be repeated here. Dissolve chloride of calcium in alcohol till the solution is saturated; steep mealed powder in it till it has thoroughly imbibed the alcohol and with it the chloride of calcium. Dry the mealed powder completely, and preserve it so in a closely stoppered bottle. When required for use, a few minutes exposure to the air will, by absorption, render the powder sufficiently moist for use; this may be known by its showing a tendency to collect together into small granules. It may then be used in precisely the same manner as the sulphide of copper composition. Twelve or fourteen trial fuzes have been fired with this composition in succession without failure, but it has not yet been employed in place of the magnet fuze composition; the trial was considered to prove that it was sufficiently certain for ordinary use. Mealed powder may also be moistened to the proper degree for priming fuzes by simply folding a small quantity in thin cloth, and breathing through it. It is apt, however, to dry too soon, and it is not by any means certain of ignition. Nothing further need be said on the subject of *firing* charges, but it may be added that the charges in common use are 25 and 50 ℔. ones, contained in tin cylinders. For use in depths of 15 feet and less, these cylinders require no strenthening, but for greater depths they should be strengthened with either stays or rings.

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* Could not be depended on during the hot winds or very dry weather.—W. J. C.

369. It will render this account more complete, to give a few instances of the demolition of trees, out of the number that have been removed this year.

In December, a large semul tree, lying 200 feet from the banks at a village called Chupree, was removed by blasting. The depth of water at the root, which lay upstream was 20 feet, and the current 2½ miles per hour. A number of separate branches spread out under and above water, and were demolished by separate charges of 25 to 50 ℔s. of powder. The root and stem gave most difficulty; the latter was however broken by two successive charges and separated and dragged to shore by crab-capstans. The root which spread out in irregular masses to a diameter of 20 feet facing the current, resisted a great number of charges, and several cylinders were broken on its projections; others of the charges broke off portions, but brought other new ones up to the surface. The tree was finally demolished after the expenditure of 850 ℔s. of powder. It would have been a manifest saving of time if a 400 ℔. charge could have been placed near the root, but the strength of the current, and the shape of the root, rendered it impossible.* The crab-capstans employed were roughly made, but have proved very serviceable. They are a convenient mode of obtaining great power, and a few carpenters and blacksmiths can make up one in a day or two.

In February, a large tree lying near the bank at the village of Tajpoor was removed. The stem was a mass of wood of about 10 feet in diameter, and the same in length. The branches were demolished in the ordinary way, but 50 ℔. charges had no effect on the stem. As its upper side projected above the surface of the water, it was ultimately split up by small charges placed in holes bored in the wood. Here also a charge of 300 or 400 lbs., if effective, would have saved time; but neither was there a good position for one, nor do I believe that it would have had any further effect than to throw the stem a short distance to one side or other, as the wood was perfectly sound, and of great strength.

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* Large boats could not safely be got into position in front of such a tree, and even if they could a cask large enough to contain 400 lbs. of powder would offer such a surface to the current as to be quite unmanageable; in some positions a cask may be sunk by another plan, described further on.

Near the same place a large tree lying half on the bank and half in water was demolished by a 200 lb. charge, followed by a few small ones The charge was placed in a cask under a hollow of the tree and in the water; the timber directly over the charge was about 12 feet thick, and embraced a palm tree that had grown with it. The timber around it was completely shattered by the explosion, but the palm itself was unhurt. Here the good effect of the charge was due to the timber being rather decayed, and to the good position in which it was placed.

In February, two trees, each 9 or 10 feet in diameter, were removed from the river at the village of Belthfah. The water was too shallow for the use of large charges. On one of them a few 25 to 50 lb. charges were first employed, and the stem was lifted out of the sand so as partly to project above water; it was then split up by small blasts placed in the wood, and its demolition completed with 25 and 50 lb. charges. The other tree was removed in the same manner, and in both cases the fragments, which were large, were dragged out by three capstans working together, and hauled up the main bank by an English gyn. Attempts made at the same place to remove a sunken banyan tree were unsuccessful. The roots resisted several small charges, and ultimately a charge of 165 lbs., and a force of 10 tons applied by means of capstans and cables, had no effect in tearing them asunder.

In February, a large tree lying on the sands above the water level was demolished by means of two 25 lb. charges, fired simultaneously in the following manner:—From the main wire of the battery, a branch was led to each charge, and as the cylinders lay in dry sand, whereas a moist connection is necessary to complete the return circuit, the return wires of the fuzes were connected with metal rods driven down into the sand till moisture was reached. To make the connection more perfect, water was poured over each cylinder and the sand round it. The battery was 400 yards away at the edge of the river. The return wire and plate were immersed in the water as usual. Both charges ignited perfectly simultaneously.

In March a large tree lying in deep water and a strong current at the village of Tickyah, was partially removed. Here also two charges were fired simultaneously, but with little effect; ultimately a charge of 450 lbs. was sunk and fired in the following manner:—A cask was prepared and tarred, and two rings of hoop-iron were nailed on its ends, so as to project from its sides and allow it to slide down a rod. A bamboo 4 inches in diameter was driven in the best spot available, and the cask was passed on to this by means of the rings; it then stood floating on the water in an upright position and empty, but with the fuzes prepared and inserted. In this case the independent fuzes were employed, as it would have been a difficult matter to recover the cask had one failed. The cask was filled and sunk in its place in a depth of 20 feet, by weights; the bamboo was securely stayed against the tree, and the main wire being connected with one of the fuzes, the boats were drawn away, and the charge fired.* The effect was not so good as might have been expected; some lower branches were separated and the tree was thrown into an upright position, but the stem was quite uninjured. The remaining operations require no notice.

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* In this manner the drag of the current on the cask was rendered harmless, and in spite of it, the charge was successfully sunk into its position under a perfect network of branches, in a place where it would have been quite impossible to bring a large boat.

A tree buried in the sand and liable to become dangerous on the shifting of the channel, was attacked in the following manner:—Its position and size were first ascertained with iron sounding rods. The stem was found to be 8 feet under the sand, and 7 feet 9 inches under the water level. A good position being selected, an iron tube 11 feet 6 inches long and 1 foot in diameter, was driven down beside it to a depth of 11 feet by means of a *ringing* engine. The tube was then bored out to a depth of 10 feet with a boring tool 10 inches in diameter, and provided with a leather sand valve. A 50 lb. charge was passed down the tube to that depth, and the tube was drawn by a differential pulley hung to the *ringing* engine. The charge was fired by means of a tin tube and pellet fuze but without much effect. It was neither large enough, nor had it been placed deep enough. The tube should have been driven 12 feet deep, and a 100 lb. charge placed at a lower level than the stem. Time did not admit of repeating the operation, but the more dangerous part of the tree was removed by other means.

In this operation the Ringing engine was worked in the following way:—The rope attached to the ram was passed down, and through a block at the rear of the engine it was carried a long distance to the rear, attached to a peg and worked alternately by two parties, one of which took it up when the other dropped it, and the ram had fallen. In this manner nearly double the ordinary number of blows were delivered in a minute, and the men were not fatigued to the usual extent; but of course a double working party was necessary.

A large tree, lying in the sands near a village called Gyaspoor, was removed by small blasts fired in holes made by means of a lever drill. This drill, which was made up out in camp, consisted of an iron frame, carrying a wheel 1 foot in diameter and working on a vertical axis. The frame was provided with keys for clamping it on a square iron-rod 5 feet long, and pointed at one end. This rod could be readily hammered into the stem of any tree it was required to bore, and the drill clamped to it could thus be brought to bear in any desired direction—vertical, sloping, or horizontal—the axis of the wheel was pierced to carry a square iron-rod, in the lower end of which the drill bits were fixed. The upper end was pointed, and pressure was applied to it by means of a lever clamped at any required height to the rod driven into the timber. The drill was driven from a 3-feet wheel placed in any convenient position; it was capable of boring 3-inch holes with moderate rapidity.

370. The following account of the removal of kunkur banks, is by the same officer:—

The features that these rocks usually present have been already described, and it only remains to state the means that have been employed in attempts to remove them. The first trials were made last year on a small rock of thin kunkur, lying in from 2 to 6 feet of water, and in a strong current. The apparatus employed was a species of small cofferdam of a portable character, consisting of an outer and inner frame and sheeting, and including between them 2 feet 6 inches thickness of strong clay puddle. The space enclosed was a rectangle of 4 feet 6 inches by 3 feet 6 inches, the object being to dry a space sufficient for a miner to work in, and drive a shaft down through the kunkur, in which a large charge might be placed and fired. The outer sheeting of the dam was supported by four frames, rectangular in shape, and each 10 feet by 3 feet 6 inches high, braced diagonally and made of 3¼ inches sál scantlings. These frames when bolted together at the angles formed a square enclosure, within which the sheeting was put down vertically in 6 inch widths. The sheeting was supported at the back by longitudinal pieces parallel to the top and bottom rails of each frame, and 2¼ inches within them. These pieces could be put in position after the frames had been bolted together.

The inner framing was constructed in the same manner, only smaller, so as to allow the space between the walls required for puddling. The surface of the rock being very irregular and steep, it was necessary to put down the the cofferdam in the following manner :—Two boats were anchored over the rocks, and the outer frames previously bolted together so as to form a square enclosure, were let down into the water. A few pieces of sheeting were then dropped in at the angles, and wedged when resting on the rock. The position and stability of the frame being thus secured, the remaining sheeting and the inner frame were rapidly put in, and the puddling commenced. The attempt to dry the dam failed; it was found that the substratum was sand, and the water came up through cracks with which the surface of the kunkur was covered; but there is no doubt that this kind of dam could be used occasionally with advantage where the material to be removed is solid rock or kunkur underlain with clay; it is very portable, and could be put down and taken up much more rapidly than a dam supported by any arrangement of jumpers driven into the rock.

371. The next attempt on the same rock was made with boring tools of rough construction. A portion of the kunkur in 4 feet depth of water having been broken up, an attempt was made to bore down, through the substratum, with the object of placing a 50 or 60 lb. charge at a depth of 6 feet, or thereabouts, below the kunkur. This attempt also failed from the fact of the sandy substratum being too fluid to retain any hole.

Trials were next made on a rock 80 feet long by 50 feet in width, and partly above water; the substratum in this case being clay, the boring tools proved quite effective. The operation of placing and firing the charges ultimately took the following shape :—A 2-inch iron-bar was first driven down into the kunkur to a depth of 6 or 7 feet, and drawn: into the hole thus formed, a small charge of powder contained in a thin cylinder of tin was inserted to a depth of 6 feet and fired. It was found that this charge by its explosion produced a narrow crater in the kunkur about 6 feet deep, and after clearing the hole with a boring tool about 1 foot in diameter, a 50 ℔. charge was readily placed at a depth of 6 feet under the kunkur. whether under or above water. It made little or no difference in the rapidity of the operation whether the kunkur lay under or over water. The hole having been tamped, the charge was fired with the pellet fuze.* producing a crater of about 18 feet in diameter, and 6 or 7 feet deep. In this manner the rock was rapidily blown away to a depth of 6 feet under-water, the whole operation not lasting more than ten days, and had arrangements been more perfect, this time would have been shortened very much.

372. In the beginning of the present season, attempts were again made on kunkur underlain with sand, and under 3 feet of water. The following method was now adopted:—Boats were prepared with framing. and planks sufficiently strong to bear a heavy strain; they were anchored over the rock with an interval of a few feet between them, and lashed together by cross-ties. A light triangle was erected on the boat, and from it was first suspended a beam of wood, shod with a heavy cast-iron pile-shoe, and slung from a pulley. This was worked up and down like the ram of a Ringing engine till the surface of the kunkur was completely broken up over a small space. On the spot thus broken up, an iron-tube 11 feet 6 inches long and 1 foot in diameter, was now placed, and driven by a ram slung from the triangle, and worked as before described. When driven to a depth of 7 feet, it was bored out, and a charge of 50 ℔s. placed at a depth of 6 feet under the kunkur. The tube was then drawn with a differential pulley, and the boats being removed, the charge was fired by means of Bickford's fuze, producing a crater 16 feet in diameter and 5 feet deep. The operation occupied about 8 hours, but it was not repeated because the river was too high at the time to make it of any real advantage except as an experiment.

373. Since that time no operations have been undertaken against kunkur rocks, except the following, which was also purely experimental.

The kunkur beds at Hurdee are the most extensive on the Gogra; they lie at various depths, and several rocks jut above the surface, or are just concealed by it when the river is at its lowest level. But whatever their total extent may be, there is no doubt that the removal of about 10,000 square, or 20,000 cubic, yards of the most prominent rocks would greatly improve the channel. It remains to be seen then to what extent the experiments that have been made justify us in supposing that this can be done within a reasonable time and at moderate cost. As in the previous experiments, boats were moored over the rock; this time in from 4 feet 6 inches to 5 feet of water, and a current of more than 2 miles per hour. The other arrangements were the same as before, but as the kunkur here lay to an indefinite depth, and partially mixed with clay, the tube before used was not necessary. A 2-inch iron-bar was driven straight down into the kunkur to a depth of 6 feet, and drawn by means of a differential pulley assisted by block tackle worked from a capstan. The hole thus made was slightly rymed out with an iron tool for the purpose, and a slender sál pile was driven down, deepening and widening the hole to a diameter of 3 inches;* it was rapidly withdrawn, and a charge of 8 lbs. contained in a tin cylinder was pressed down into the hole to a depth of 8 feet. This was fired, and the hole produced, which was as narrow at the mouth as at the bottom, was cleared out with a boring tool 1 foot 7 inches in diameter and 16 feet long; into this a diver descended, and reported that it was about 2 feet in diameter the whole way down and 8 feet in depth. A charge of 60 lbs. was all that was available at the time, and it failed through the breaking of the cylinder; but this failure in no way affects the principle; moreover other charges were fired successfully under the same rock, in the same manner; but this instance is given, as it was the most successful one in the product of a large and deep shaft.

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* This was one of the earliest operations, and no galvanic or magnetic battery was at hand

374. The centre of the above charge was at a depth of 7 feet 6 inches under the surface of the kunkur, and with a further depth of 4 feet 6 inches of water above it. Now, although we have no exact data for the influence of this depth of water, we may presume that it will necessitate a considerable increase of the charge in order to produce the same effect as in air. The charges ordinarily used to produce three lined craters in earth are calculated as $\frac{1}{4}$th the cube of the Line of Least Resistance, whereas I propose here to employ charges of $\frac{1}{3}$rd cube of L. L. R. On this supposition, the quantity of powder required at that depth to produce a three-lined crater would be 140 lbs; and we may, perhaps, calculate that on an average, charges of 150 lbs. would produce craters of 20 feet in diameter; where the water was deep, they would, perhaps, produce less than this; where shallow, more. Part of the débris from such craters would generally lie about the edges, part would be blown to a considerable distance, and part would fall back into the crater where it would be harmless, being at a considerable depth under the surface. On the débris which lay round the hole, the current would act powerfully, separating the clay and reducing its bulk to less than half the original; the nodules of kunkur themselves would be carried away in the floods, or even if they remained they would be at a much greater depth under water, and could never bind again into a surface as compact as the original. Thus it seems likely that, even were the blasting operations not assisted by dredging, the result would still be to break-up, disintegrate, and reduce in bulk the whole rock, and leave the kunkur in such a condition as to be acted on by the succeeding floods, and to be gradually carried away altogether.

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* In loose kunkur of this description a wooden pile will act effectually as a wedge to widen a hole already formed, but it cannot be driven in the first instance even if shod with iron.

375. On such an extensive rock surface as that of Hurdee, it would be easy to accommodate three or more working parties,*—we may suppose three,—and it is not too much to assume that, with the proper appliances, each party would fire three charges in a day. Eight charges a day would be a fair allowance for the whole three parties, and supposing such charges to be placed at two-lined intervals, or 14 feet apart, the whole number of charges required to break up a surface of 10,000 square yards would be 462, the quantity of gunpowder about 70,000 lbs., and the number of days in which it could be done 58; but allowing for unavoidable delays and occasional bad weather, it would be well to calculate on the operation lasting three months, which is about the length of the season most favorable for such work.

The cost of the operation may be roughly estimated as follows:—

	RS.
Working parties, including crews of three pair of boats, 20 men each, at an average rate of wages of Rs. 5, .	300
Three Lallas in charge of boats, at Rs. 15, ...	45
Hire of additional boats for carriage of men and materials to and from shore, ...	100
Total .	455 monthly.

As experiment has not yet decided how far it would be necessary to assist the action of the charges by dredging away the débris into deep water, the hire of the three boats, at Rs. 30 per month each, will be added to the above :—

	RS.
Brought forward, ...	445
Hire of three boats for dredging at Rs. 30 per month, each,	90
Total . .	535
Total boat hire and labor for three months, . .	1,605

The work would of course require the presence of an Engineer and

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* Each pair of boats would take up a considerable space in order to keep the moorings clear of each other.

European Overseer, whose salaries however will not appear here. The expenditure on materials would be trifling except that on vessels to contain the charges. This expenditure could be reduced to a minimum by employing either 100 or 200 lb. charges, in either of which cases, the original powder barrels would be placed in the mines, and no expense would be incurred beyond that of making them water-proof.

If 150 lb. charges be employed, as here contemplated, the cost of tin cylinders should be added to that of preparing the barrels, as it would be necessary to employ for each 150 lb. charge, one 100 lb. barrel, and one 50 lb. cylinder.

	RS.
Cost of preparing 462 barrels, at 8 annas each,	231
462 tin cylinders, at Rs 1 each,	462
Total,	693
Making a total expenditure during the progress of the works of	2,298

370. The first cost of preparations and of a stock would be as follows:—

The boats employed for boring and for placing the charges should belong to Government; but their cost would be a charge only against the first operations, as the same boats would answer for all subsequent ones, as well as for any of the ordinary works of the season. Allowing two 150-maund boats to each working party, at a cost of Rs. 1 per maund of tonnage, the estimate would be as follows:—

Six 150-maund boats, at Rs. 150 each,	900
Decking and strengthening do., at Rs. 50,	300
Total	1,200

PLANT.	RS.
Six 2 feet diameter boring tools, at Rs. 50,	300
Three triangles, at Rs. 50,	150
Three differential pulleys, at Rs. 100,	300
Three crab winches, at Rs. 100,	300
Miscellaneous,	150
Total	1,200
Grand total first cost of boats and plant,	2,400
Grand total cost of labor and materials,	2,298

The above estimate for plant does not include jumpers, hammers, Ringing engines for driving the jumpers,* by which are here meant simply pointed bars of iron, not steeled; blocks and some smaller stores, which in this case happen to be in hand at present. Had these to be included, they would increase the estimate by about Rs. 400.

Taking the figures as they stand, and adding 10 per cent. to cover contingencies and the wear and tear of tools and cordage:—

	Rs.
The total first cost of boats and plant will be, . .	2,640
The total cost of labor, boat-hire and materials, . .	2,523

These amounts represent the cost of the operations on a sunken rock, as it would be charged against the sum appropriated for works, and it takes no account of the cost of European supervision and of gunpowder, which would not be so; but where the expenditure of gunpowder is so great, its cost, if it entered the estimate would become by far the largest item. In the foregoing estimate the cost has been worked out by calculating merely from the extent of the surface of rock to be demolished, and it has been tacitly assumed that the charges would in every case reduce the kunkur to a safe depth below the surface. This depth may, and has been assumed as 6 feet, but every additional foot that could be obtained would be of value, and be worth a proportionate increase of expenditure. In order to obtain a clear depth of 6 feet in every case, it would, perhaps, be necessary to use larger mines where the kunkur lay nearer the surface, and smaller where it lay deeper. But it is thought that the average taken, namely, 150 lbs. for each mine, is on the safe side of the truth.

377. The difficulty previously mentioned, namely, that of entirely dispersing the kunkur thrown up by the explosion of a charge, might be partially obviated by using rather larger charges than those proposed, or by dredging, or by both methods. Is is a matter for experiment, as no sufficient data for it exist at present; but it is suggested that it would be economical to work only on the deeper part of a reef according to this method; and where cofferdams could be constructed, to employ them for the removal of all rock within 2 feet 6 inches or 3 feet of the surface, as in such shallow water they would be readily and cheaply constructed. Cofferdams appear to have been employed on the Ganges river works with a certain degree of success, but at an enormously greater cost than that here estimated; there are also certain objections to their use, which cannot be gone into here, and many of the rocks spoken of have a sandy substratum which would not admit of their employment.

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* The jumpers on all the rocks yet tried could be hammered directly down through the kunkur, which of course can be much better done with a Ringing engine than by hand. In the case of block kunkur it would be necessary to work the jumper in the ordinary fashion.

The above description and estimate will answer their purpose, if they be considered to show the feasibility of removing kunkur rocks on a large scale at a reasonable cost. On such a scale as here contemplated their removal is—by the ordinary methods of blasting—by no means a simple Engineering problem, and an inspection of the rocks themselves, with masses jutting up here and there and the current racing over sunken beds between them, is not at all calculated to re-assure the Engineer, who has not at the time decided on his means of attack.

378. 4. The means to be resorted to for obtaining a suitable depth of water for navigation, are all comprised in the above paragraphs. The expensive system termed lock and dam navigation, often used both in America and England, which consists in dividing the stream into several suitable reaches or pools, by forming dams to keep the water in the pool at a constant head, and by passing from one pool to another by locks at the ends of the dams, could, it is evident, be rarely applicable to Indian streams. Something in this direction might, however, be tried on such a stream as the Ravee, where the river is of a manageable size, and the results to be obtained by its navigation are very important.

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